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DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

CHEMICAL COMPOSITION OF IGNEOUS ROCKS

EXPRESSED BY MEANS OF DIAGRAMS

WITH REFERENCE TO ROCK CLASSIFICATION ON A QUANTITATIVE
CHEMICO-MINERALOGICAL BASIS

BY

JOSEPH PAXSON HIDDINGS



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LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,

UNITED STATES GEOLOGICAL SURVEY,

Washington, D. C., May 26, 1903.

SIR: I have the honor to transmit herewith a manuscript by Joseph Paxson Iddings entitled "Chemical composition of igneous rocks expressed by means of diagrams, with reference to rock classification on a quantitative chemico-mineralogical basis," and to recommend that it be published as a Professional Paper.

The significance of a large number of chemical analyses of igneous rocks, with their many variable elements, each having a great range, is somewhat difficult of comprehension to all geologists and petrographers who have not devoted much time to their study. Mr. Iddings presents a method of expressing the most significant factors in each analysis by a simple diagram, and by grouping these individual diagrams on a certain principle he has succeeded in representing the great variation in composition and the chemical relationships of almost the entire range of igneous rocks in a way that is comprehensible at a glance. The facts thus brought out are discussed by him in their bearing on petrographic system. As a successful attempt at the elucidation of a complex problem the paper is of importance to all students of igneous rocks.

Very respectfully,

WHITMAN CROSS,

Geologist in Charge, Section of Petrology.

Hon. CHARLES D. WALCOTT,

Director United States Geological Survey.

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**CHEMICAL COMPOSITION OF IGNEOUS ROCKS EXPRESSED BY MEANS
OF DIAGRAMS, WITH REFERENCE TO ROCK CLASSIFICATION
ON A QUANTITATIVE CHEMICO-MINERALOGICAL BASIS.**

By JOSEPH PAXSON IDDINGS.

INTRODUCTION.

The value of graphical methods for expressing relative quantities has been well established in all kinds of statistical exposition and discussion. Their use in conveying definite conceptions of relative quantities of chemical and mineral components of rocks is becoming more and more frequent, and the value of the results in some cases can not be overestimated. This is especially true when a series or group of rocks is being considered. The intricate variations in the amounts of numerous mineral components, or of chemical components, baffle most attempts to comprehend their interrelationships by simple contemplation or by study of the numbers in which they may be expressed. Many facts and relations are overlooked which are readily observed when diagrams are used to represent numerical figures. Moreover, visual memory is sufficiently developed in most persons to enable them to carry in mind simple geometrical forms, where it does not permit them to recollect manifold assemblages of oft-repeated numbers. Mental impressions of simple diagrams are, therefore, more definite and lasting and enable the student to store up a much greater amount of quantitative data than he could otherwise acquire.

Evidence of the appreciation of this fact by petrographers is found in the increasing use of diagrams in petrographical literature, and a brief sketch of the growth and elaboration of graphical methods for presenting quantitative petrographical data will serve as an appropriate introduction to the subject in hand. From this notice will be excluded those diagrams which serve to connect the names of rocks in series after the manner of expressing genealogical relationships, in which diagrams the space relationships are not strictly quantitative. Such diagrams have been used by George H. Williams, H. O. Lang, and other petrographers.

HISTORICAL REVIEW.

Among the earliest diagrams employed to represent relative quantities of rock constituents are those used by Reyer in 1877.^a They are more or less generalized expressions, in one instance of the varying proportions of the chief oxide components in rocks and meteorites; in another of the varying amounts of the commoner rock-making minerals capable of being developed in rock magmas with different silica content. The diagrams used are rectangles subdivided by curved lines corresponding to the variations mentioned. Other diagrams express the variations of different kinds of rocks with respect to silica; the relation between specific gravity, silica percentage, and texture of mineralogically similar rocks; and the relative abundance of rocks of different compositions and textures.

Subsequently in his work, *Theoretische Geologie*,^b he reproduces two of these diagrams and introduces others showing the proportions of chemical components in two series of minerals (feldspars and pyroxenes) and others showing the proportions of the chief minerals in three kinds of rocks. One diagram consists of adjacent, long, narrow rectangles, each divided into rectangular parts proportionate to the percentages of the oxide constituents in certain kinds of rocks, from granite to gabbro, and in five types of meteorites.

Judd,^c in his book on *Volcanoes*, in 1881, makes use of a diagram to represent the varying amounts of chemical elements in rocks and meteorites. It is similar in form to one used by Reyer, already described.

In 1890 the author^d constructed diagrams to exhibit the variation in chemical composition of rocks forming geologically related groups or series. In these diagrams the quantitative data represent specific analyses of different rocks in each series. The oxide constituents of each rock are referred to rectangular coordinates, the silica being plotted as abscissas, and the other oxides—alumina, ferric and ferrous iron, magnesia, lime, soda, and potash—being plotted as ordinates. Straight lines connecting successive loci of any one oxide, as those of alumina, indicate the variations in the amount of each constituent in the rock series. This is the chief feature brought out by these diagrams, the range and character of the variations being shown.

Similar diagrams have been used by Dakyns and Teall^e to illustrate the chemical variations in the plutonic rocks of Garabal Hills and Meall Braec.

^a Reyer, E., *Beitrag zur Physik der Eruptionen*. Vienna, 1877.

^b Reyer, E., *Theoretische Geologie*. Stuttgart, 1883.

^c Judd, J. W., *Volcanoes*. New York, 1881, p. 322, fig. 88.

^d Iddings, J. P., The mineral composition and geological occurrence of certain igneous rocks in the Yellowstone National Park: *Bull. Philos. Soc. Washington*, vol. 11, January, 1890, pp. 207 and 211; also in *Twelfth Ann. Rept. U. S. Geol. Survey*, 1892, pp. 629 and 649; *Mon. U. S. Geol. Survey*, vol. 32, pt. 2, pp. 119 and 136; *Origin of igneous rocks*, *Bull. Philos. Soc. Washington*, vol. 12, June, 1892, and in *Jour. Geol.*, vol. 1, 1893, p. 173.

^e Dakyns, J. R., and Teall, J. J. H., *Quart. Jour. Geol. Soc. London*, vol. 48, 1892, p. 116.

Scotland; by Washington to express the chemical variation in the volcanic rocks of Aegina and Methana, Grecian Archipelago,^a and in the rocks of Magnet Cove, Arkansas;^b and by Cross^c to show the chemical composition of the rocks of the Rosita Volcano, Colorado.

Harker^d has employed the same form of diagram, but has used atomic ratios of the chemical elements instead of the oxides, to show the variations in the rocks of Carrock Fell, England. Subsequently he modified it slightly by using percentages of the oxide components instead of their molecular proportions to discuss the possibility of distinguishing igneous rock series from mixed igneous rocks.^e

Loewinson-Lessing^f has also made use of this method of exhibiting the variability of chemical composition in eruptive rocks, illustrating the great divergence in the composition of rocks classed under one name in the qualitative system and also the differences in composition of average magmas.

In 1900 Pirsson^g pointed out the possibility of relating the variations in the chemical composition of rocks of one geological body to their position in that body by introducing their space relations into this form of diagram. He accomplished it by letting the abscissas represent distances in the rock body between the various rocks analyzed. By this modification of the diagram just described, he showed that the variations in chemical composition in such cases follow very regular laws, and with one or two elements determined in a variety of the rock the remainder may be found by means of the diagram.

Similar diagrams have since been used by Washington in discussing the differentiation in the rocks of Magnet Cove.^h

Pirsson has also used a somewhat similar diagram to represent the variations in mineral composition of rocks of Yogo Peak, Little Belt Mountains, Montana.ⁱ

In 1896 Becke^j represented the chemical composition of igneous rocks by diagrams of two kinds, constructed in a manner different from that of those just described. The first is a modification of a three-coordinate diagram for three variables, whose sum is a constant, based upon an equilateral triangle. The three factors chosen are Ca, Na, K. The zero point of the coordinate axis is the center of the triangle. From this point three axes run to the corners of the triangle, one for each of the elements, Ca, Na, K. The spot within the

^a Washington, H. S., *Jour. Geol.*, vol. 3, 1895, p. 160.

^b Washington, H. S., *Bull. Geol. Soc. America*, vol. 11, 1900, p. 404.

^c Cross, W., *Seventeenth Ann. Rept. U. S. Geol. Survey*, pt. 2, 1896, p. 324.

^d Harker, A., *Quart. Jour. Geol. Soc. London*, vol. 51, 1895, p. 146.

^e Harker, A., *Jour. Geol.*, vol. 8, 1900, pp. 389-399.

^f Loewinson-Lessing, F., *Compte rendu Congrès Géol. International, Seventh session, St. Petersburg, 1899*, Pls. I, II, and III.

^g Pirsson, L. V., *Twentieth Ann. Rept. U. S. Geol. Survey*, pt. 3, 1900, p. 569 et seq.

^h Washington, H. S., *Bull. Geol. Soc. America*, vol. 11, 1900, p. 651.

ⁱ *Op. cit.*, p. 568.

^j Becke, F., *Min. Pet. Mitth.*, vol. 16, 1897, p. 315-320.

triangle determined by the values of Ca, Na, K, in a given rock analysis is the locus of the analysis (*Analyseort*). The various positions of these spots indicate the relative amounts of the elements named in the rocks compared. The other chemical elements in the rocks are represented on a second diagram supposed to stand at right angles to the plane of the first. It is drawn with rectangular coordinates, the abscissas being proportional to the ratio $\frac{\text{Ca}}{\text{Ca} + \text{Na} + \text{K}}$, and the ordinates representing the values of Si, Al, Fe, Mg. Each of these elements is located by a spot in the diagram.

In January, 1897, Michel Lévy^a devised diagrams to exhibit certain chemico-mineralogical characters of igneous rocks, a single diagram representing an individual rock. The component oxides are first distributed into two groups, those that may combine with Al_2O_3 to form feldspars and those that may not. All the Al_2O_3 is set aside for feldspars, and to it is allotted K_2O , Na_2O , and sufficient CaO to satisfy it. An excess of CaO is placed with iron and magnesia. Silica may be introduced into the diagram or omitted, and in a subsequent publication^b in the same year is expressed only in numbers stating the percentage. Rectangular coordinates are used and the values of the components are laid off on two axes intersecting at the zero point. Below this point is plotted the percentage of potash, and also that of iron oxide. To the right of the zero point is plotted the percentage of soda which may combine with alumina. In this direction, also, may be plotted the percentage of silica. Above the zero point is plotted the lime which may combine with alumina, and also the percentage of magnesia. If there is more lime than will satisfy the alumina remaining after potash and soda have been satisfied, this lime is plotted to the left of the zero point. Triangles are constructed by connecting the end of the potash line with that of the soda line, and the soda with feldspathic lime. Magnesia is connected with nonfeldspathic lime, and this with iron. Two triangles to the right of the y axis give an indication of the feldspathic constituents of the rock. The other two triangles to the left of the y axis represent the nonaluminous constituents. Modifications of the diagrams enter when there is an excess of alumina over alkalies and lime, and again when alumina is less than the alkalies.

Michel Lévy in the publication last cited also employs diagrams showing curves of variation for the percentages of the chemical components when subdivided in the manner just described.

These triangular diagrams have been used by Lacroix in describing the basic rocks accompanying the lherzolites and ophites of the Pyrenees,^c and also in his

^a Lévy, A. Michel, Bull. Serv. Carte géol. France, vol. 9, No. 57, 1897, p. 38 and Pls. VII, VIII.

^b Lévy, A. Michel, Bull. Soc. géol. France, 3d series, vol. 25, 1897, Pls. X to XV.

^c Lacroix, A., Compte rendu Congrès Géol. International, Eighth session, Paris, 1901, Part II, pp. 834, 835.

work on the alkaline rocks of the petrographical province of Ampasindava, Madagascar.^a

In May, 1897, Brögger^b presented a modification of the individual diagrams devised by Michel Lévy. This was done in illustrating the chemical composition of the group of rocks associated with the laurdalite of the Christiania region. Brögger's diagrams are composed of four coordinates in a plane intersecting in a common zero point. One is horizontal, another vertical, and the other two inclined, one 60° to the right, the other 60° to the left of the vertical axis. On these axes are plotted the molecular proportions of the chief oxide components of a rock. On the upper vertical axis are plotted the molecules of CaO, on the lower vertical axis the Al₂O₃. On the horizontal axis right and left is plotted the SiO₂, half and half. On the upper right inclined axis is plotted MgO; on the upper left one, the FeO + Fe₂O₃, indicated separately. On the lower right inclined axis is plotted K₂O, and on the lower left one Na₂O. The extremities of adjacent axes are connected by lines. These diagrams show at a glance the relative proportions of the molecules of the oxide constituents of each rock. The amount of CaO capable of being combined with Al₂O₃, not combined with K₂O and Na₂O, can be readily found by measuring the lengths of the several axes. The introduction of the silica and alumina adds to the instructiveness of this form of diagram.

Diagrams of this type have been employed by Hobbs^c to express the average composition of groups of rocks classed together under various divisions of the qualitative system in general use at the present time. In these diagrams the inclined axes stand at 45° to the vertical axis.

Hackman^d has made use of both the Becke and the Brögger diagrams to express chemical relations among the rocks associated with ijolite in Kuusamo, Finland.

Rosenbusch^e uses narrow rectangular diagrams to express the relative proportions of the chemical elements (*Metallatome*) in two series of 26 rocks; one, a foyaite-thermalite series, the other a granitodiorite and gabbro-peridotite series.

In February, 1898, the author^f in an essay on rock classification, and later in another essay, made use of diagrams exhibiting the variations of rock analyses with reference to percentage of silica and alkali-silica ratio. These are constructed by using the silica percentages as abscissas, the zero point being to the

^a Lacroix, A., *Nouv. Arch. Museum Hist. Nat.*, 4th series, I, Paris, 1902, p. 180 et seq.

^b Brögger, W. C., *Die Eruptivgesteine des Kristianlagebietes*. III. *Videnskabselskabets Skrifter*. I. Math.-Naturv. Kl. 1897. No. 6. Christiania, 1898.

^c Hobbs, W. H., *Jour. Geol.*, vol. 8, 1900, pp. 1-31.

^d Hackman, V., *Bull. Com. Geol. Finlande*, vol. 11, Helsingfors, 1900.

^e Rosenbusch, H., *Elemente der Gesteinslehre*. Stuttgart, 1898.

^f Iddings, J. P., *Jour. Geol.*, vol. 6, 1898, pp. 92-111, 219-237.

right of the diagram, and 100 to the left. The ordinates represent the ratios obtained by dividing the sum of the molecular proportions of the alkalies, K_2O and Na_2O , by that of silica. The locus of each analysis is indicated by a round spot or by figures of other shapes.

In the same year, 1898, Michel Lévy^a presented a new mode of coordination of diagrams to represent rock magmas, based in a measure on those just published by the author, to some features of which Michel Lévy took exception. These diagrams by Michel Lévy give the loci of rock analyses referred to two coordinates in the plane of drawing, and also to a third axis projected on the same plane. The abscissas (x) represent the silica percentages in the "white components" (éléments blancs) of the rocks compared. The ordinates (y) represent the sum of the percentages of K_2O , Na_2O , and the CaO which may enter feldspar combined with Al_2O_3 . The third coordinates (z) represent the percentages of MgO , FeO , Fe_2O_3 , CaO , and SiO_2 in the ferromagnesian components of the rocks. The loci of the analyses are fixed by the rectangular coordinates x and y . Their relation to the axis z is indicated by their position with reference to diagonal lines representing the projected traces of certain planes with an inclined plane through z .

The usefulness of this diagram, which appears when the compositions of restricted groups of rocks are illustrated, is seriously impaired by repeated overlapping when many kinds of rocks are taken into account. The method undertakes to distribute the analyses with respect to the relative abundance of the white (leucocratic) components—quartz and feldspathic minerals—and the dark (melanocratic) ferromagnesian components in the first instance, and also with respect to the silica content of the leucocratic components.

It is clear that rocks containing various amounts of nephelite, leucite, and anorthite molecules with closely similar percentages of silica will be mingled together in the same part of the diagram, and that rocks with preponderant ferromagnesian minerals, since they are plotted wholly on a basis of characters belonging to the subordinate feldspathic minerals, will be indiscriminately mingled in one portion of the diagram.

In 1899 Loewinson-Lessing,^b in his studies of eruptive rocks, an abstract of which was presented, without diagrams, to the International Geological Congress at St. Petersburg in 1897, makes use of two forms of diagrams, one after the method of the author, already alluded to, and another based on the method of relative rectangular areas used by Reyer. The diagram represents the various molecular proportions of the chemical components of a rock, or may represent the average of a group of rocks. It is a rectangular area divided by horizontal

^a Lévy, A. Michel, Bull. Soc. géol. France, 3d series, vol. 26, 1898, Pls. III to VI.

^b Loc. cit.

lines into spaces whose vertical dimensions correspond to the proportions of SiO_2 , R_2O_3 , RO , and R_2O in each case. These rectangles are subdivided by vertical lines into spaces whose horizontal dimensions correspond to the proportions of Al_2O_3 and Fe_2O_3 in R_2O_3 , of FeO , CaO , and MgO in RO , and of K_2O and Na_2O in R_2O .

In 1900 Mügge^a devised a form of diagram to express the proportions of the chemical components of rocks, based upon some features of Michel Lévy's and Brögger's diagrams. Several modifications of the diagram were suggested by Mügge. It will be sufficient to describe the form used by him to illustrate the composition of a number of selected rocks. The relative quantities of the oxide components, expressed molecularly, are plotted on four coordinate axes in one plane intersecting in a zero point and making equal angles with one another. One is vertical, one horizontal, and two inclined at 45° . The silica is represented by an octagonal area, constructed by plotting one-eighth of the total silica plus and minus on each axis. The other components are plotted outside this area on particular axes by adding their values to the silica already plotted. K_2O is plotted on the upper left inclined axis, Na_2O on the upper right one, MgO on the lower left inclined axis, CaO on the lower right one. FeO is plotted on the lower vertical axis, followed by Fe_2O_3 in the same direction. Al_2O_3 is divided into three parts, when sufficient, the first, equal molecularly to K_2O , is plotted to the left on the horizontal axis. A second, equal to the Na_2O is plotted upward on the vertical axis, and the remainder of the Al_2O_3 is plotted to the right on the horizontal axis. When there is less Al_2O_3 than $\text{K}_2\text{O} + \text{Na}_2\text{O}$, enough Fe_2O_3 is added to Al_2O_3 upward on the vertical axis to equal Na_2O . In this manner the relative amounts of potash-alumina molecules, soda-alumina molecules, and lime-alumina molecules are indicated.

In 1900 and 1901 Osann^b made use of several types of diagrams to illustrate chemical characteristics of igneous rocks in his essay on a chemical classification of igneous rocks.

One is a triangular diagram somewhat similar to that used by Becke, exhibiting the distribution of analyses with respect to three coordinate axes making equal angles with one another. The three chemical factors of rocks employed in their comparison are chemico-mineralogical to some extent. One factor (A) consists of the sum of the percentages of K_2O and Na_2O which may be combined with Al_2O_3 in equal molecular amount. A second factor (C) represents the percentage of CaO which may be combined with Al_2O_3 in equal molecular amount. The third factor (F) represents the sum of the percentages of the remaining CaO ,

^a Mügge, O., Neues Jahrb. Min., Geol. und Pal., 1900, vol. 1, pp. 100-112, Pls. V-VII.

^b Osann, A., Min. Pet. Mitth., vol. 19, 1900, Pls. IV-VIII, XXV; vol. 20, 1901, Pls. VIII-XIV.

MgO, FeO. The sum of these is assumed to be a constant, and their relative proportions are determined on a basis of 20 units. With these three variables the position of a rock analysis within the equilateral triangle is located.

A second form of diagram expresses the variation in silica and alkalinity in certain rocks by means of lines connecting loci of analyses referred to two rectangular coordinates, the abscissas corresponding to the alkalinity, and the ordinates to the silica percentage. Another diagram of the same type exhibits the variability of different kinds of rock with respect to the relative proportions of soda and potash.

A third form of diagram is composed of narrow rectangles, whose lengths correspond to the range of variation in silica ratios for different kinds of rocks. The rectangles are placed by the side of one another, with their longer diameters adjusted to one ordinate representing values of silica ratios.

In 1902 Reid^a used an equilateral triangle whose sides are divided into 100 parts, as a basis on which to plot the oxide components of igneous rocks.

PURPOSE OF THE DIAGRAMS.

A study of the various diagrams that have been employed by petrographers shows that their value depends upon the readiness with which their significance may be grasped and the use that is made of them. The first condition varies directly as the simplicity of the method of construction, both as to geometrical form and as to the factors on which they are based. The simpler the form of the diagram and the more characteristic its shape, the more definite the visual impression and the stronger the hold on the mind. It is also self-evident that the simpler the factors entering into it the better. The quantitative values of single rock components are simpler conceptions than intricate ratios and functions involving several different rock components. Moreover, a diagram is comparatively worthless unless it can be made to convey some definite impression not otherwise obtainable, or obtainable only with difficulty. Its employment should have some specific object. It is hoped that the diagrams presented in this paper will justify themselves and will produce certain definite impressions on the minds of petrographers who may study them.

The author's first purpose in constructing the accompanying diagrams is to express in the simplest graphical manner the chief chemical composition of all kinds of igneous rocks in a form that will permit the student to compare them at a glance and obtain a comprehensive view of the whole range of differences.

The diagrams are intended to exhibit the manifold character of the variations of the chemical components of rocks, and their extent. They are to show the

^a Reid, J. A., Bull. Dept. Geol. Univ. California, vol. 3, 1902, p. 18.

gradual character of the variations; the transitions from rocks of one composition to those of another; and the distribution of the rocks throughout the range of their variations.

They are to demonstrate the absence of clusters of analyses in definite parts of the whole system and the absence of "natural" subdivisions of rocks on a basis of chemical composition.

They are to show the possibility of continuous series of rocks with diverse compositions, and to illustrate the chemical identity of rocks belonging to different genetic families.

Finally the diagrams exhibit the character of the quantitative classification of igneous rocks proposed by Cross, Iddings, Pirsson, and Washington, the range of composition of the five classes, as well as of the orders, ranges, and subranges.

CONSTRUCTION OF THE DIAGRAMS.

As will be seen by looking at the plates, the diagrams are combinations of two kinds already in use. They consist of assemblages of individual rock diagrams, which are modifications of those devised by Michel Lévy and Brögger, the individual diagrams being arranged in a multiple diagram previously used by the author. The first are used to exhibit the chief chemical components of each rock taken into consideration; the second, to arrange these in an orderly manner for comparison with one another.

The small, individual diagrams are modified forms of those by Brögger. They are planned to exhibit the relative amounts of the chief oxide components of igneous rocks, namely: SiO_2 , Al_2O_3 , $\text{Fe}_2\text{O}_3 + \text{FeO}$, MgO , CaO , Na_2O , K_2O , and also TiO_2 . Other components are usually so slight that they are negligible in diagrams of such small scale. Owing to the fact that the small diagrams are arranged in the large diagram according to the silica, it is not necessary for the purposes of this paper to introduce SiO_2 into the construction of the individual diagram. The relative amount of SiO_2 is expressed by the position of the small diagram in the large one. This simplifies the small diagram.

The chemical components of rocks may be compared with one another as oxides of metals or as metals. As oxides, the form in which they are expressed in chemical analyses of rocks, they may be compared by means of percentage weights or of molecular proportions. As metals they would be compared by molecular or atomic proportions.

The use of oxides instead of metal elements is the more convenient method of comparison. It bears a more obvious and direct relation to the rock analysis and requires less effort to apply. It is as valuable in the discussion of chemico-mineralogical relationships as the use of metal elements. It has, therefore, been adopted in constructing these diagrams.

The value of basing the comparisons upon molecular proportions instead of percentage weights rests upon the fact that the chemical equivalency of the components is molecular or atomic, and that in this form they may be readily converted into mineral molecules for purposes of discussion and rock classification.

For purposes of comparison in diagrams of this type it is not necessary to reduce the original analysis to a sum of exactly 100. So far as the small individual diagrams are concerned the amount of change produced in the lengths of the lines would not be appreciable. Further, all elementary lines in one diagram would be affected in like proportion and the shape of the figure would remain unchanged, even could the alteration in the length of the lines be made visible. It would affect to a variable degree the position of the small diagrams within the large one in the direction of the silica abscissa, which will be discussed later.

The small, individual diagrams are constructed to exhibit the molecular proportions of the component oxides: Al_2O_3 , $\text{Fe}_2\text{O}_3 + \text{FeO}$, MgO , CaO , Na_2O , K_2O , and TiO_2 . These are derived directly from the rock analysis by dividing the percentage weight of each oxide by its molecular weight. There is no further reduction. They are used in the proportions in which they are found in the rock, the assumption being that equal weights of different rocks are being compared.

Following Brögger's method, the several values of these oxides are plotted on coordinate axes in one place, intersecting at a common zero point. But the arrangement is different. For convenience in drawing on square-ruled paper the axes chosen are vertical, horizontal, and two at 45° to these. The simple, approximate relation between the sides and hypotenuse of a 45° triangle, namely, that when the hypotenuse is 10 units the sides are 7 units each (more exactly 7.071) allows the values to be readily plotted by assuming the diagonal of each square of the ruled paper to be 5 and the side $3\frac{1}{2}$. With larger diagrams and more exact requirements more accurate methods of plotting may be employed.

Since the small diagrams are to be compared by means of the multiple one, the position of the Brögger diagrams is inverted to conform more closely to the manner of constructing the large diagram. In the multiple diagram the more alkalic, and consequently more alkali-feldspathic, members of the series of rocks compared occur in the upper part; the less alkalic, and more ferromagnesian, in the lower part. So the alumina and alkalies are placed in the upper part of the individual diagrams, the iron and magnesia in the lower. The mode of construction is as follows: Al_2O_3 is plotted upward on the vertical axis; K_2O upward to the left on one inclined axis; Na_2O upward to the right on the other inclined axis; CaO is plotted downward on the vertical axis; MgO downward to the right; $\text{FeO} + 2\text{Fe}_2\text{O}_3$ downward to the left; and TiO_2 , when present in appreciable amount, is plotted to the left on the horizontal axis. The end of the Al_2O_3 ordinate is connected by lines with the ends of the K_2O and Na_2O ordinates,

producing two triangles having a common side—the Al_2O_3 ordinate—and one angle the same in each— 45° . Consequently the areas of the two triangles are proportional to the lengths of the K_2O and Na_2O ordinates. The relative impressions produced by these two triangles, colored green and yellow in the diagrams, are quantitatively the same as the relations between the molecular proportions of K_2O and Na_2O in the rock.

The end of the CaO ordinate is connected with the ends of the MgO and $\text{FeO}+2\text{Fe}_2\text{O}_3$ ordinate, making two triangles, colored blue and red in the diagrams, whose areas bear the same proportion to one another as the ratio between the molecules of MgO and the iron converted to FeO .

When TiO_2 is represented, the end of its ordinate is connected with that of the FeO ordinate.

The FeO and Fe_2O_3 are combined chiefly for simplicity, and the Fe_2O_3 is reduced to FeO because there is then a more uniform basis of comparison and a means of avoiding the analytical defects or errors in the determination of the two oxides of iron. The combination prevents a proper conception of the possibilities of mineral molecular combination so far as the iron is concerned, but this is beyond the adaptability of the diagrams in a strict sense.

It is evident that diagrams constructed on the molecular proportions of the oxide components of rocks may be easily converted into others, based on the proportions of the metal elements, by doubling the lengths of the three upper ordinates, Al_2O_3 , K_2O , Na_2O . The upper half of each diagram would be double its former size, while the angular shape of the whole would remain the same.

The multiple diagram, by which the small individual ones are arranged for comparison and study, is constructed in the manner already described in the article on rock classification previously cited. It is intended to exhibit the distribution or variation of igneous rock analyses with respect to the silica and alkalies. The reasons for choosing these two factors are: First, the important rôle played by silica, the most abundant chemical component, and that which is dominant in the development of quartz, orthoclase, albite, leucite, or nephelite, orthorhombic pyroxene or olivine; second, the equally important rôle played by the alkalies in conditioning the character of the feldspathic mineral components of rocks, which are the preponderant ones in the great majority of cases; third, the fact that the other chemical components—lime, magnesia, and iron oxide—sustain to a considerable extent a reciprocal relation to those just mentioned. The greater the silica the less the content in lime, magnesia, and iron oxide. The same is true in general for the alkalies and these oxides.

One of the chief purposes of the diagram is to distribute the rocks in an orderly manner, so that unlike rocks shall be separated from one another as widely as possible and gradations between the extremes shall be made evident.

The silica is made the abscissa because it is the greater component and has the widest range. It is plotted in percentages instead of molecular proportions because the process is simpler, and as it is not brought into immediate quantitative relations to the linear elements of the individual diagrams there is no occasion for its quantitative linear comparison with them. Moreover, the large diagram could not be constructed on the same scale of units as the individual diagrams. It is therefore simpler and more convenient to use the percentage of silica given in the analyses.

The vertical ordinates represent the ratio between the sum of the molecular proportions of the alkalies ($K_2O + Na_2O$) and of the silica — $\frac{(K_2O + Na_2O)}{SiO_2}$. This ratio was selected because of the relation between the development of the alkali-feldspathic minerals in highly feldspathic rocks and the ratio between the alkalies and silica in their magmas; the more siliceous ones yielding more orthoclase or albite, the less siliceous ones more leucite or nephelite. It is not a definite relationship in rocks generally, and, as Michel Lévy has pointed out, the character of the diagram would not have been altered materially had the vertical ordinates been made to correspond directly to the sum of the alkalies. In this case the curved lines which represent the loci of pure quartz-albite-nephelite rocks and quartz-orthoclase-leucite rocks would be straight lines instead of hyperbolas, as in the diagrams here used. There would be a slightly different vertical spacing of the analyses on individual diagrams. They would be spread more on the left side of the ordinate of 60 per cent SiO_2 , and condensed more on the right of it. The multiple diagrams would be more simply constructed. Otherwise the results would be alike.

With diagrams constructed by using ratios between two or more rock components it matters not whether the analyses discussed by it are reduced to anhydrous compounds, or whether their summation is exactly 100. The ratio between the alkalies and silica is not affected by readjusting the analysis. The ordinate of an analysis so located is not changed by readjusting the percentages in the analysis, but the abscissa would be affected by changing the silica percentage. The position of an analysis would be shifted horizontally to the left or right according as the percentage of silica is raised or lowered.

The zero point of each individual diagram is located in the multiple diagram by reference to the silica percentage and the alkali-silica ratio of the analysis it represents. In some instances several individual diagrams belong so close together that they would overlap, so as to prevent their shapes from being easily seen. One or more of them is moved to the nearest available space in the multiple diagram. From this it happens that the distribution of the analyses in

the large diagram is not strictly correct in the more crowded portions of it. A more exact representation of the distribution is given in another form of multiple diagrams on a smaller scale, in which round spots take the place of the individual diagrams.

ROCK ANALYSES USED IN CONSTRUCTING DIAGRAMS.

Having described the methods by which the diagrams are constructed, a more important matter to be considered is the data to be used—the rock analyses to be compared by them.

Analyses have been selected from all sources available, but not all analyses. It is important that they be correctly made and from good material. These conditions, however, can not always be recognized or known without careful study of the publications in which the analyses appear, and not always then. The collection is not above criticism in this respect. However, care was exercised to omit obviously defective analyses, as well as those from plainly declared altered rocks, except in cases where the altered form may be assumed to correspond approximately to the fresh rock, with the addition of water of hydration. For the strongly ferromagnesian rocks such analyses have been taken sometimes in default of better.

The analyses represent as many varieties of igneous rocks as could be found, with as wide a range as possible. Many analyses closely similar to those introduced into the large diagrams have been omitted because there was not space for them. Consequently the diagrams do not show the proper proportions between the commoner and rarer varieties of rocks. This can be shown by plotting the loci of all acceptable analyses by means of spots in a multiple diagram of fairly large scale. This has been done in constructing the diagram on Pl. VIII, which is composed of 2,000 analyses.

It was thought unnecessary to reprint the analyses themselves, for the reason that nearly all of them will be found in the collection of rock analyses made by Dr. Henry S. Washington and published by the United States Geological Survey,^a and a large part of them also in Bulletin of the United States Geological Survey No. 168. Many of them will be found in Rosenbusch's *Elemente der Gesteinslehre*. So that these collections should be used in connection with the diagrams. For this reason reference is given in many cases to these publications, and to others where numerous analyses are assembled, instead of to the original sources, as the more convenient method of finding them.

A list of the analyses used in the diagrams is given. Their positions on the diagrams may be found by means of the silica percentage and alkali-silica

^a Chemical analyses of igneous rocks from 1884 to 1900: Prof. Paper U. S. Geol. Survey No. 14.

ratio, which are stated in each case, besides the position given them when placed differently.

They are classified according to the quantitative classification, and the author wishes to express his thanks to Dr. Washington for the labor he has bestowed on the comparison of the list with his collection and for the correction of errors that appeared in the list. He is indebted to him also for valuable additions to it.

The list is far from complete, and petrographers may add to it and to the diagrams data which should have been included. But it seems as though enough has been introduced to accomplish the purpose for which the diagrams were prepared.

In order to shorten the references in the lists, a number of abbreviations are used which are given alphabetically.

ABBREVIATIONS EMPLOYED IN BIBLIOGRAPHIC REFERENCES.

- A. G. American Geologist. Minneapolis.
 A. J. S. American Journal of Science. New Haven.
 A. W. B. Sitzungsberichte der Königl. Preuss. Akad. der Wissensch. Berlin.
 A. W. W. Sitzungsberichte der K. Akad. Wissensch. Wien.
 B. C. G. F. Bulletin de la Commission géologique de Finlande. Helsingfors.
 B. G. S. A. Bulletin of the Geological Society of America. Rochester.
 B. M. A. Bergens Museums Aarbog.
 Bull. 168. Bulletin of the U. S. Geological Survey, No. 168. Washington, 1900.
 C. G. I. Congrès géologique International, Compte Rendu, VIII session. Paris.
 E. K. Die Eruptivgesteine des Kristiania-gebietes, W. C. Brögger. Christiania. I, 1894; II, 1895; III, 1898.
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 G. F. S. F. Geol. Fören. i Stockholm Förhandl.
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 J. G. The Journal of Geology. Chicago.
 O. N. Recherches géologiques et pétrographiques sur l'Oural du Nord, Duparc et Pearce. Part I. Geneva, 1902.
 M. M. Matériaux pour la Minéralogie de Madagascar, A. Lacroix. Nouvelles Archives du Muséum. 4th series, Vol. I. Paris, 1902.
 N. J. Neues Jahrbuch für Mineralogie, Geologie, etc.
 Q. J. G. S. Quarterly Journal of the Geological Society of London.
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 R. T. Roth's tables of rock analyses. Beiträge zur Petrographie der Plutonischen Gesteine. Berlin.
 S. M. Q. School of Mines Quarterly. New York.
 T. M. P. M. Tschermak's Min. u. Petr. Mitth. Vienna.
 W. T. Washington's tables of chemical analyses of igneous rocks from 1884 to 1900. Professional Paper U. S. Geological Survey, No. 14, Washington, 1903.
 Z. D. g. G. Zeitschrift d. Deutschen geol. Gesellschaft. Berlin.
 Z. K. Zeitschrift für Krystallographie.
 Z. P. G. Zeitschrift für Praktische Geologie. Berlin.
 Fortieth Par. U. S. Geol. Expl. Fortieth Parallel. Washington.

CLASSIFIED LIST OF ANALYSES USED IN CONSTRUCTING DIAGRAMS.

CLASS I. PERSALANE.

ORDER 3. COLUMBARE.

RANG 1. ALASKASE.

SUBRANG 1. ———.

(I. 3, 1, 1.)

Silica con- tent.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
79.25	0.067	Porphyry.....	Harz Mountains.....	R. T., 1861, 7.

SUBRANG 2. MAGDEBURGOSE.

(I. 3, 1, 2.)

79.75	0.062	Quartz-porphyry	Blowing Rock, Watauga County, N. C.	Bull. 168, 52.—W. T.
78.86	.079	Felsite-porphyry	Fichtelgebirge, Bavaria	R. T., 1879, XX.
76.10	.085	Granite.....	Crystal Falls district, Mich.....	Bull. 168, 66.—W. T.
75.39	.080	Rhyolite.....	Silver Cliff, Colo.....	Bull. 168, 149.—W. T.
74.40	.079	Granite.....	Pikes Peak district, Colo.....	Bull. 168, 142.—W. T.

SUBRANG 3. ALASKOSE.

(I. 3, 1, 3.)

80.24	0.070	Granite.....	Wexford, Ireland.....	R. T., 1861-2.
79.57	.070	Rhyolite.....	Montgomery County, N. C.....	Bull. 168, 53.—W. T.
77.68	.077	Granitite	Eldorado County, Cal	Bull. 168, 199.—W. T.
77.68	.075 (77.6)	Quartz-porphyry	Tryberg Fall, Black Forest.....	N. J., 1883, II, 29.—W. T.
77.59	.069	Rhyolite.....	Hauraki Goldfield, New Zealand.....	Q. J. G. S., 1899, LV, 467.—W. T.
77.33	.079 (.078)	Alaskite	Tordrillo Mountains, Alaska	Bull. 168, 228.—W. T.
77.20	.080	Quartz-porphyry	Kroftkollen, Norway	Z. K., XVI, 77.—W. T.
77.05	.080	Aplite	Butte, Mont	Bull. 168, 118.—W. T.
77.03	.081 (76.8-.082)	Granitite	Pikes Peak district, Colo.....	Bull. 168, 142.—W. T.
77.02	.077 (77.1)	Granite.....	Platte Canyon, Colo	Bull. 168, 164.—W. T.
76.87	.078	Aplite	Butte, Mont	Bull. 168, 118.—W. T.
76.73	.077 (76.6)	Aplitic granophyre...	Hennum, Norway	Z. K., XVI, 77.—W. T.
76.10	.063	Muscovite-granite....	Omeo, Victoria	Trans. R. S. Vict.—W. T.
75.84	.081	Tordrillite.....	Tordrillo Mountains, Alaska	Bull. 168, 229.—W. T.
75.52	.080 (75.7)	Obsidian	Obsidian Cliff, Yellowstone Park.....	Bull. 168, 104.—W. T.
74.70	.083	do	do	Do.
74.24	.069	Rhyolite.....	Plumas County, Cal	Bull. 168, 178.—W. T.
73.11	.082 (73.0)	Pitchstone.....	Rosita, Colo	Bull. 168, 150.—W. T.

SUBRANG 4. ———.

(I. 3, 1, 4.)

83.08	0.054	Spherulitic rock	Wales.....	Teall, British Petrography, 339.
82.80	.049	Perlite.....	Monte Menone	R. T., 1869, XC.
76.00	.067	Granite.....	Plumas County, Cal	Bull. 168, 187.—W. T.
75.19	.076 (75.1)	Rhyolite.....	Madison Plateau, Yellowstone Park..	Bull. 168, 106.—W. T.

CHEMICAL COMPOSITION OF IGNEOUS ROCKS.

Classified list of analyses used in constructing diagrams—Continued.

SUBRANG 5. WESTPHALOSE.

(I. 3, 1, 5.)

Silica content.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
83.57	0.053	Quartz-keratophyre ..	Westphalia	N. J., 1893, VIII, 616.—W. T.
80.42	.059	do	do	N. J., 1893, VIII, 632.—W. T.
77.32	.061 (.083)	Granite.....	Roddö, Sweden.....	W. T.

RANG 2. ALSBACHASE.

SUBRANG 2. MIHALOSE.

(I. 3, 2, 2.)

73.15	0.055	Rhyolite.....	Nagy-Mihaly, Hungary	W. T.
73.07	.074	do	Washoe, Nev	Bull. 168, 174.—W. T.
72.68	.054	do	Nagy-Mihaly, Hungary.....	W. T.
70.59	.057	do	do	Do.

SUBRANG 3. TEHAMOSE.

(I. 3, 2, 3.)

79.95	0.049	Felsite-porphry	Bohemia	R. T., 1884, XVIII.
77.34	.069	Aplite	Kirnechthal, Vosges	Rosenbusch, El., 207.
76.12	.059	Granitite	Riesengebirge, Silesia	N. J., 1898, XII, 233.—W. T.
75.89	.069 (75.8)	Rhyolite.....	Mount Sheridan, Yellowstone Park..	Bull. 168, 105.—W. T.
75.34	.076	do	Elephants Back, Yellowstone Park ..	Do.
75.21	.072	Granitite	Riesengebirge, Silesia	N. J., 1898, XII, 233.—W. T.
74.65	.074	Rhyolite.....	Tehama County, Cal	Bull. 168, 178.—W. T.
74.41	.067	Granite.....	Riesengebirge, Silesia	N. J., 1898, XII, 233.—W. T.
74.34	.072	Rhyolite.....	Butte district, Mont	Bull. 168, 119.—W. T.
73.62	.079 (73.7)	do	Tehama County, Cal	Bull. 168, 178.—W. T.
72.37	.058	Granitite	Riesengebirge, Silesia	N. J., 1898, XII, 232.—W. T.
72.15	.067	do	do	Do.
72.04	.058	do	do	Do.
72.01	.073	Quartz-porphry	Eureka, Nev	U. S. G. S., Mon. XX, 228.
71.45	.054	Granitite	Sykesville, Md	Bull. 168, 47.—W. T.

SUBRANG 4. ALSBACHOSE.

(I. 3, 2, 4.)

78.75	0.052	Granite.....	Storgord, Finland.....	R. T., 1869, XL.
77.35	.052	do	Riesengebirge, Silesia	N. J., 1898, XII, 233.—W. T.
74.65	.064	Granitite	do	Do.
74.13	.077	Alsbachite.....	Melibocus, Odenwald	Rosenbusch, El., 207.—W. T.
73.08	.080 (72.9)	Rhyolite.....	Waihi, Hauraki, New Zealand	Q. J. G. S., 1899, LV, 467.—W. T.
72.89	.056	Granitite	Riesengebirge, Silesia	N. J., 1898, XII, 232.—W. T.

SUBRANG 5. YUKONOSE.

(I. 3, 2, 5.)

74.79	0.067	Tonalite-aplite	Yukon River, Alaska.....	Bull. 168, 229.—W. T.
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RANG 3. RIESENAGE.

SUBRANG 2. ———.

(I. 3, 3, 2.)

Silica content.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
72.11	0.041	"Schliere" in granite	Riesengebirge, Silesia	N. J., 1898, XII, 235.—W. T.
71.14	.055	Toscanite	Rocca Strada, Italy	J. G., V, 363.—W. T.
66.86	.062	Granite-porphry	Nieder Modau, Hesse	W. T.

SUBRANG 3. RIESENAGE.

(I. 3, 3, 3.)

76.82	0.037	Granitite	Riesengebirge, Silesia	N. J., 1898, XII, 233.—W. T.
75.27	.036	Granite	do	Do.
75.21	.048	Granitite	do	Do.
78.00	.049	Toscanite	Rocca Strada, Italy	J. G., V, 363.—W. T.
72.92	.040	Granitite	Riesengebirge, Silesia	N. J., 1898, XII, 232.—W. T.
72.71	.038	do	do	Do.
69.04	.047	do	do	N. J., 1898, XII, 234.—W. T.

SUBRANG 4. ———.

(I. 3, 3, 4.)

76.13	0.055 (76.2)	Granite	Riesengebirge, Silesia	N. J., 1898, XII, 233.—W. T.
72.81	.041	Granitite	do	N. J., 1898, XII, 232.—W. T.

SUBRANG 5. VULCANAGE.

(I. 3, 3, 5.)

72.24	0.062	Quartz-diorite-porphyry.	Calaveras County, Cal.	Bull. 168, 203.—W. T.
66.99	.051	Vulcanite	Vulcano, Lipari	B. G. S. A., V, 601.—W. T.

RANG 4. ———.

SUBRANG 2. ———.

(I. 3, 4, 2.)

68.87	0.028	"Schliere" in granite	Riesengebirge, Silesia	N. J., 1898, XII, 235.—W. T.
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Classified list of analyses used in constructing diagrams—Continued.

ORDER 4. BRITANNARE.

RANG 1. LIPARASE.

SUBRANG 1. LEBACHOSE.

(I. 4, 1, 1.)

Silica con- tent.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
69.06	0.117 (69.3)	Quartz-orthoclasite...	Thüringerwald, Prussia.....	W. T.
68.18	.107	Quartz-porphry	Hummelberg, Prussia.....	Do.

SUBRANG 2. OMEOSE.

(I. 4, 1, 2.)

75.20	0.096	Rhyolite	Silver Cliff, Colo.....	Bull. 168, 149.—W. T.
75.07	.084	do	Pine Nut Canyon, Nev	Fortieth Par., I, 652.
74.62	.095	do	Humboldt Sink Group, Nev.....	Do.
74.24	.089	Rapakivi	Livland, Finland.....	R. T., 1878, X.
71.09	.112	Aplite	Satteljoch, Predazzo, Tyrol	K. A. W. W., CXI, I, 266.
70.91	.121	Graphie granite	Omeo, Victoria	Trans. R. S. Vict.—W. T.
68.99	.115	Pitchstone	Ponza, Italy	R. T., 1879, LII.
68.87	.084	Granite.....	Omeo, Victoria.....	Trans. R. S. Vict.—W. T.

SUBRANG 3. LIPAROSE.

(I. 4, 1, 3.)

77.61	0.088	Granite.....	Cape Ann, Mass	J. G. VI, 793.—W. T.
76.49	.092	Paisanite.....	Magnolia, Mass.....	J. G. VII, 113.—W. T.
76.33	.092	Graphie granite	Hochland	R. T., 1869, XLII.
76.30	.098	Alaskite	Alaska	Bull. 168, 228.—W. T.
76.20	.091	Obsidian	Obsidian Hill, N. Mex.....	Bull. 168, 172.—W. T.
76.05	.092	Aplitic granophyre...	Konerudwege, Norway.....	Z. K., XVI, 77.—W. T.
75.71	.094 (75.6)	Rhyolite	Great Paint Pots, Yellowstone Park..	Bull. 168, 105.—W. T.
75.44	.094	Comendite	Iskagan Bay, Siberia	A. J. S., XII, 1902, 180.—W. T.
75.44	.089	Rhyolite	Fish Creek Mountains, Nev	Fortieth Par., I, 652.
75.30	.082	do	Rimini, Mont	Bull. 168, 119.—W. T.
75.17	.085	Granitite	Pikes Peak district, Colo.....	Bull. 168, 142.—W. T.
74.90	.094	Rhyolite.....	Castle Mountain district, Mont	Bull. 168, 129.—W. T.
74.87	.084	Granite	Brookville, Md.....	Bull. 168, 46.—W. T.
74.76	.098	Comendite	Comende, San Pietro, Sardinia.....	Rosenbusch, El., 257.—W. T.
74.45	.090	Rhyolite.....	Chalk Mountain, Colo	Bull. 168, 156.—W. T.
74.05	.096	Obsidian	Mono Craters, Cal	Bull. 168, 219.—W. T.
73.93	.100	Granite	Quincy, Mass.....	J. G., VI, 793.—W. T.
73.69	.100	Granite-porphry.....	Mount Ascutney, Vt	Bull. 168, 25.—W. T.
73.51	.094 (73.4)	Granitite	Pikes Peak district, Colo	Bull. 168, 142.—W. T.
73.35	.106	Paisanite	Mosques Canyon, Tex.....	T. M. P. M., XV, 439.—W. T.
73.09	.085	Granite-porphry.....	Albany, N. H.....	A. J. S., XX, 1881, 25.
73.08	.104	Syenite-porphry.....	Mount Ascutney, Vt.....	Bull. 168, 24.—W. T.
72.88	.093	Aplite-granite	Castle Mountain district, Mont	Bull. 168, 129.—W. T.
72.48	.099	Granite	do	Do.
72.35	.093	do	Ironton, Mo	Bull. 168, 60.—W. T.
72.26	.101	do	Albany, N. H.....	A. J. S., XXI, 1881, 25.
72.06	.107	do	Stony Creek, Conn	B. G. S. A., X, 376.—W. T.

Classified list of analyses used in constructing diagrams—Continued.

SUBRANG 3. LIPAROSE—Continued.

Silica content.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
71.90	.102	Granitite	Mount Ascutney, Vt.....	Bull. 168, 24.—W. T.
71.88	.096	Porphyry	Ironton, Mo.....	Bull. 168, 60.—W. T.
71.67	.101	Quartz-porphyry	Castle Mountain district, Mont	Bull. 168, 129.—W. T.
71.56	.086	Pitchstone.....	Silver Cliff, Colo.....	Bull. 168, 159.—W. T.
71.49	.109	Quartz-porphyry	Gislerud, Norway	Z. K., XVI, 46.—W. T.
71.07	.087	Granite-porphyry	Albany, N. H.....	A. J. S., XXI, 1881, 26.
70.92	.096 (70.7)	Rhyolite	Upper Geyser Basin, Yellowstone Park.	Bull. 168, 104.—W. T.
70.23	.113	Keratophyre	Marblehead Neck, Mass.....	Bull. 168, 34.—W. T.
70.09	.092	Orthoclase-porphyry	Cornon, Tyrol.....	R. T., 1879, XXVIII.
70.01	.113	Obsidian	Palmerola, Italy.....	R. T., 1879, LII.
69.91	.119	Ægirite-granite	Milask, Ural Mountains.....	A. J. S., XIII, 1902, 180.—W. T.
69.89	.098	Rhyolite	Nathrop, Colo	Bull. 168, 164.—W. T.
68.95	.144	Groerdite	W. Aker, Norway.....	E. K., I, 199.—W. T.
68.71	.114	Quartz-pantellerite ..	Vieja Mountains, San Carlos, Tex....	Bull. 168, 61.—W. T.
68.65	.110 (68.5)	Granite-syenite-porphyry.	Little Rocky Mountains, Mont.....	Bull. 168, 134.—W. T.
68.34	.129	Quartz-syenite.....	Bearpaw Mountains, Mont.....	Bull. 68, 135.—W. T.
66.40	.097 (66.7)	Quartz-syenite-porphyry.	Fjelebus, Norway.....	Z. K., XVI, 46.—W. T.

SUBRANG 4. KALLERUDOSE.

(I. 4, 1, 4.)

75.92	0.093 (75.8-.094)	Granitite	Pikes Peak district, Colo	Bull. 168, 142.—W. T.
73.61	.089	Rhyolite	Oyacachi, South America	R. T., 1879, LIV.
73.50	.096 (73.8)	Quartz-bearing bas-tonite.	Ampangarinana, Madagascar.....	M. M., 55.
72.56	.099 (72.8)	Rhyolitic pitchstone ..	Castle Mountain district, Mont	Bull. 168, 129.—W. T.
72.46	.095	Rhyolite.....	Guomani, Ecuador, South America ..	R. T., 1879, LIV.
71.65	.119	Soda granite.....	Hougnatten, Norway.....	E. K., I, 198.—W. T.

SUBRANG 5. NOYANGOSE.

(I. 4, 1, 5.)

77.66	0.087 (77.9-.086)	Quartz-keratophyre ..	Omeo, Victoria.....	Rosenbusch, El., 260.—W. T.
75.78	.091	Granite.....	Rice Point, Duluth, Minn.....	21st Ann. Rept., Surv. Minn., 41.—W. T.
75.46	.097	Soda-rhyolite.....	Berkeley, Cal.....	Rosenbusch, El., 260.—W. T.

RANG 2. TOSCANASE.

SUBRANG 2. DELLENÖSE.

(I. 4, 2, 2.)

69.19	0.102	Granite.....	Tryberg Fall, Schwarzwald	N. J., 1883, II.
68.36	.078	Dellenite	Dellen, Helsingland, Sweden	E. K., II, 59.—W. T.
66.24	.093	Toscanite.....	Monte Cucco, Italy.....	J. G., V, 362.—W. T.
65.19	.093	do	Tolfa, Italy.....	Do.

CHEMICAL COMPOSITION OF IGNEOUS ROCKS.

Classified list of analyses used in constructing diagrams—Continued.

SUBRANG 3. TOSCANOSE.

(I. 4, 2, 3.)

Silica con- tent.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
76.48	0.087	Aplite	Dargo, Victoria.....	Trans. R. S. Vict.—W. T.
76.03	.081	do	Sierra County, Cal.....	Bull. 168, 192.—W. T.
76.00	.087	Granodiorite-aplite.....	Downieville area, Cal.....	J. G., VII, 160.—W. T.
75.97	.079 (76.1-.078)	Aplite	Sierra County, Cal.....	Bull. 168, 192.—W. T.
75.74	.086	Granite.....	Lier, Norway.....	Z. K., XVI, 77.—W. T.
75.08	.084 (75.0)	Obsidian	Laguna de Maricunga, Chile.....	Z. D. J., G. LI, 4.
75.01	.086 (75.1-.088)	Alaskite	Alaska.....	Bull. 168, 228.—W. T.
74.95	.088	Rhyolite	Montezuma Mountains, Nev.....	Fortieth Par., I, 652.
74.60	.081	do	Shasta County, Cal.....	Bull. 168, 178.—W. T.
74.49	.088 (74.6)	do	Thomas Range, Utah.....	Bull. 168, 168.—W. T.
74.37	.085	Granitite	Crazy Mountains, Mont.....	Bull. 168, 120.—W. T.
73.84	.083	Rhyolite-perlite	Midway Basin, Yellowstone Park.....	Bull. 168, 108.—W. T.
73.70	.092	Granite.....	Peterhead, Scotland.....	R. T., 1884, XIV.
73.64	.083	Rhyolite.....	Lassen trail, Tehama County, Cal.....	Bull. 168, 178.—W. T.
73.51	.097	Obsidian	Modoc County, Cal.....	Bull. 168, 217.—W. T.
73.38	.080	Granite.....	Lake Raslangen, Sweden.....	W. T.
73.12	.087	Quartz-porphry	Little Belt Mountains, Mont.....	Bull. 168, 125.—W. T.
72.57	.090	Granite.....	Gullford, Md.....	Bull. 168, 46.—W. T.
72.40	.086	Rhyolite	Mount Stover, Cal.....	Bull. 168, 178.—W. T.
71.85	.087 (72.0)	do	Tower Creek, Yellowstone Park.....	Bull. 168, 104.—W. T.
71.79	.082 (71.7)	Granitite	Woodstock, Md.....	Bull. 168, 46.—W. T.
71.78	.085	Granite.....	Cottonwood Canyon, Utah.....	Fortieth Par., I, 110.
71.53	.070	Granitite	Riesengebirge, Silesia.....	N. J., 1898, XII, 232.—W. T.
71.12	.098	Rhyolite.....	Ponza, Italy.....	R. T., 1879, LII.
71.08	.084 (71.0)	Granodiorite	El Capitan, Yosemite, Cal.....	Bull. 168, 207.—W. T.
70.87	.092	Rhyolite.....	Pennsylvania Hill, Silver Cliff, Colo.....	Bull. 168, 149.—W. T.
70.75	.080	Granite.....	Amador County, Cal.....	Bull. 168, 200.—W. T.
70.56	.105 (70.7)	Rhyolite.....	Ponza, Italy.....	
70.54	.107	Ægirite-granite	Løken, Norway.....	Z. K., XVI, 57.—W. T.
70.45	.084	Granite.....	Dorsey's Run, Md.....	Bull. 168, 47.—W. T.
70.29	.101	Rhyolite.....	Harlequin Canyon, Nev.....	Fortieth Par., I, 652.
69.98	.089	Dacite	Washoe, Nev.....	Bull. 168, 174.—W. T.
69.95	.098 (70.1)	Quartz-porphry	Butte district, Mont.....	Bull. 168, 119.—W. T.
69.94	.092	Granite.....	Ironton, Mo.....	Bull. 168, 60.—W. T.
69.68	.087	Granite-porphry	Little Belt Mountains, Mont.....	Bull. 168, 125.—W. T.
69.52	.108	Trachyte	Pikes Peak district, Colo.....	Bull. 168, 145.—W. T.
69.45	.097	Rhyolo-trachyte.....	Sunset Peak, Mont.....	Bull. 168, 106.—W. T.
68.88	.100	Quartz-syenite-por- phyry.....	Squam Light, Mass.....	J. G., VII, 109.—W. T.
68.68	.077	Granite.....	Eureka, Nev.....	U. S. G. S., Mon. XX, 228.
68.60	.107 (68.7)	Granite-porphry	Little Belt Mountains, Mont.....	Bull. 168, 125.—W. T.
68.58	.100	Granite.....	West Humboldt Mountains, Nev.....	Fortieth Par., I, 110.
68.55	.095	do	Shap, England.....	Q. J. G. S., 47, 276
68.42	.083 (68.2)	Quartz-monzonite	Hailey, Idaho.....	Bull. 168, 137.—W. T.
68.40	.112 (68.2)	Granite.....	Millstone Point, Conn.....	B. G. S. A., X, 375.—W. T.
68.36	.105	Nordmarkite	Gloucester, Mass.....	J. G., VI, 800.—W. T.
67.45	.084	Granodiorite	Eldorado Canyon, Cal.....	Bull. 168, 199.—W. T.
67.44	.104	Granite-syenite-por- phyry.....	Little Belt Mountains, Mont.....	Bull. 168, 127.—W. T.
67.12	.082	Granite.....	Boulder, Mont.....	Bull. 168, 118.—W. T.
67.04	.107	Quartz-syenite-por- phyry.....	Little Belt Mountains, Mont.....	Bull. 168, 127.—W. T.
66.60	.111	Akerite.....	Gloucester, Mass.....	J. G., VI, 798.—W. T.

ROCK ANALYSES USED IN CONSTRUCTING DIAGRAMS.

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Classified list of analyses used in constructing diagrams—Continued.

SUBRANG 3. TOSCANOSE—Continued.

Silica con- tent.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
66.12	.123 (66.3)	Trachyte	Wicher Mountain, Colo	Bull. 168, 145.—W. T.
65.58	.094	do	Monte Amiata, Italy	Rosenbusch, El., 269.—W. T.
65.32	.096	do	do	Do.
65.06	.092	Toscanite	do	J. G., V, 362.—W. T.
64.76	.094	Trachyte	do	Rosenbusch, El., 269.—W. T.
64.64	.114 (64.5)	Syenite	Little Belt Mountains, Mont	Bull. 168, 125.—W. T.
64.62	.118	Diorite	Mount Ascutney, Vt.	Bull. 168, 25.—W. T.
64.57	.095	Toscanite	Bracciano, Italy	J. G., V, 362.—W. T.
64.49	.103	Porphyrite	Crazy Mountains, Mont	Bull. 168, 120.—W. T.
62.38	.110	Latite	Clover Meadow, Tuolumne County, Cal.	Bull. 168, 206.—W. T.

SUBRANG 4. LASSENOSE.

(I. 4, 2, 4.)

75.50	0.083	Rhyolite	Obsidian Cliff, Yellowstone Park	Bull. 168, 104.—W. T.
73.27	.077	Granite	Florence, Mass	Bull. 168, 30.—W. T.
73.00	.075	do	Rocklin, Cal.	Bull. 168, 198.—W. T.
72.59	.083	Obsidian	Willow Park, Yellowstone Park	Bull. 168, 104.—W. T.
71.74	.075	Granite	Riesengebirge, Silesia	N. J., 1898, XII, 232.—W. T.
71.19	.073	Quartz-porphyrity	Calaveras County, Cal.	Bull. 168, 203.—W. T.
70.36	.082	Granodiorite	Enterprise, Butte County, Cal.	Bull. 168, 190.—W. T.
69.93	.109	Granite-porphyrity	Crazy Mountains, Mont	Bull. 168, 120.—W. T.
69.66	.084	Dacite	Lassen Peak, Cal	Fortieth Par., I, 652.
69.56	.076	do	Colombia, South America	J. G., I, 171.—W. T.
69.51	.083	do	Lassen Peak, Cal	Bull. 168, 179.—W. T.
69.00	.126	Quartz-lindolite	W. Aker, Norway	E. K., I, 196.—W. T.
68.72	.084 (68.8)	Dacite	Lassen Peak, Cal	Bull. 168, 180.—W. T.
68.65	.084	Quartz-monzonite	Sierra County, Cal.	Bull. 168, 192.—W. T.
68.32	.086	Dacite	Lassen Peak, Cal	Bull. 168, 179.—W. T.
68.10	.088	do	Shasta County, Cal	Bull. 168, 180.—W. T.
67.89	.088	Andesite	Buntingville, Cal	Bull. 168, 181.—W. T.
67.55	.087 (67.2)	Pitchstone	Butte district, Mont	Bull. 168, 119.—W. T.
67.49	.085 (67.6)	Dacite	Sepulchre Mountain, Yellowstone Park.	Bull. 168, 91.—W. T.
67.49	.112	Mica-dacite	Silver Cliff, Colo.	Bull. 168, 149.—W. T.
67.42	.116	Augite-soda-granite	Kekequabic Lake, Minn	A. G., XI, 385.—W. T.
67.01	.120	Alaskite-porphyrity	Alaska	Bull. 168, 228.—W. T.
66.46	.104	Dacite	Rosita, Colo	Bull. 168, 149.—W. T.
66.30	.098	Dacite-porphyrity	Shasta County, Cal	Bull. 168, 177.—W. T.
66.28	.094 (66.5)	Porphyrite	Crazy Mountains, Mont	Bull. 168, 120.—W. T.
65.87	.099	Feldspar-porphyrity	Castle Mountain district, Mont	Bull. 168, 180.—W. T.
65.78	.121	Mica-andesite	San Mateo Mountain, N. Mex.	Bull. 168, 170.—W. T.
65.64	.108	Andesite-porphyrity	Gray Peak, Yellowstone Park	Bull. 168, 107.—W. T.
64.98	.109	Oligoclase	Preston, Norway	B. M. A., 1898, VII, 47.—W. T.
62.58	.109	Syenite-porphyrity	Yogo Peak, Mont	Bull. 168, 127.—W. T.

SUBRANG 5. MARIPOSESE.

(I. 4, 2, 5.)

74.21	0.100	Soda-granite	Mariposa County, Cal	Bull. 168, 207.—W. T.
67.88	.084 (67.8)	Granite	Cavaura River, British Guiana	W. T.

CHEMICAL COMPOSITION OF IGNEOUS ROCKS.

Classified list of analyses used in constructing diagrams—Continued.

RANG 3. COLORADASE.

SUBRANG 3. AMIATOSE.

(I. 4, 3, 3.)

Silica con- tent.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
68.97	0.075	Granite.....	Lower Elsass, Voeges.....	Rosenbusch, El., 78.
65.53	.085	Trachyte.....	Monte Amiata, Italy.....	Rosenbusch, El., 269.—W. T.
65.96	.085	Quartz-porphyrte.....	Mount Carbon, Colo.....	Bull. 168, 160.—W. T.
65.18	.082	Andesite-perlite.....	Eureka, Nev.....	U. S. G. S., Mon. XX, 264.—W. T.
63.17	.088	Dacite.....	Pergamon, Asia Minor.....	A. J. S., III, 1897, 45.—W. T.
61.93	.086	Andesite.....	Kara Tash, Asia Minor.....	A. J. S., III, 1897, 45.—W. T.

SUBRANG 4. YELLOWSTONESE.

(I. 4, 3, 4.)

68.41	0.084	Dacite.....	Colombia, South America.....	J. G., I, 171.—W. T.
68.10	.065	Diorite.....	Ono, Cal.....	Bull. 168, 177.—W. T.
68.12	.078	Andesite.....	Shasta County, Cal.....	Bull. 168, 183.—W. T.
67.90	.075	Dacite.....	Colombia, South America.....	J. G., I, 171.—W. T.
66.94	.070	Andesite.....	Sierra County, Cal.....	Bull. 168, 193.—W. T.
66.65	.082	Quartz-diorite- porphyry.	do.....	Bull. 168, 192.—W. T.
66.65	.074	Granodiorite.....	Nevada City, Cal.....	Bull. 168, 194.—W. T.
65.71	.065	Banatite.....	Banat, Hungary.....	Rosenbusch, El., 140.
65.66	.072	Dacite.....	Sepulchre Mountain, Yellowstone Park.	Bull. 168, 91.—W. T.
65.63	.080	Andesite.....	Fan Creek, Yellowstone Park.....	Bull. 168, 107.—W. T.
68.60	.086 (65.7)	Quartz-mica-diorite.....	Electric Peak, Yellowstone Park.....	Bull. 168, 89.—W. T.
64.85	.084	do.....	do.....	Do.
64.61	.088	Andesite.....	Crescent Hill, Yellowstone Park.....	Bull. 168, 108.—W. T.
64.52	.080	do.....	Mount Shasta, Cal.....	Bull. 168, 176.—W. T.
64.48	.076 (64.7)	do.....	do.....	Do.
64.27	.081	do.....	Sepulchre Mountain, Yellowstone Park.	Bull. 168, 91.—W. T.
64.24	.078 (64.1)	Dacite-porphry.....	Shasta County, Cal.....	Bull. 168, 177.—W. T.
63.81	.079	Dacite.....	Mill Creek, Shasta County, Cal.....	Bull. 168, 180.—W. T.
63.42	.098	Quartz-diorite- porphyry.	Crandall Basin, Wyo.....	Bull. 168, 94.—W. T.
63.30	.087	Andesite.....	Mount Rose, Washoe, Nev.....	Fortieth Par. I, 604.
62.91	.094	Granitite.....	Dorseys Run, Md.....	Bull. 168, 47.—W. T.
62.85	.085	(?) Porphyrite-diorite.....	Mount Marcellina, Colo.....	Bull. 168, 160.—W. T.
61.42	.078	Porphyrite.....	Storm Ridge, Colo.....	Do.

SUBRANG 5. AMADOROSE.

(I. 4, 3, 5.)

69.66	0.074	Quartz-diorite-aplite.....	Amador County, Cal.....	Bull. 168, 201.—W. T.
69.34	.066	Granite.....	Saganaga Lake, Minn.....	21st Ann. Rept. Geol. Surv. Minn., 43.—W. T.

RANG 4. ———.

SUBRANG 3. ———.

(I. 4, 4, 3.)

65.81	0.047	Granite.....	Hochwald, Voeges.....	Rosenbusch, Steiger Schiefer (Strassburg, 1877), 167.
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Classified list of analyses used in constructing diagrams—Continued.

ORDER 5. CANADARE.

RANG 1. NORDMARKASE.

SUBRANG 3. PHLEGROSE.

(I. 5, 1, 3.)

Silica con- tent.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
66.13	0.130	Quartz-syenite.....	Fjelebua, Norway.....	Z. K., XVI, 46.—W. T.
66.03	.132 (65.9)	Trachyte.....	Game Ridge, Custer County, Colo....	Bull. 168, 147.—W. T.
65.43	.131	Syenite.....	Mount Ascutney, Vt.....	Bull. 168, 24.—W. T.
64.88	.128	Syenite-porphry.....	do.....	Bull. 168, 25.—W. T.
64.04	.160	Nordmarkite.....	Tonsenas, Norway.....	Z. K., XVI, 54.—W. T.
63.71	.159	Pulaskite.....	Salem Neck, Mass.....	J. G., VI, 806.—W. T.
62.30	.142	Bostonite.....	Gran, Norway.....	E. K., III, 204.—W. T.
61.92	.151	Pulaskite.....	Lokobé, Madagascar.....	M. M., 204.
61.88	.176	Trachyte.....	Marecocco, Italy.....	A. J. S., VIII, 1899, 289.—W. T.
61.62	.170 (61.2)	do.....	Monte Rotaro, Italy.....	Do.
61.45	.143 (61.3)	do.....	Maros, Celebes.....	G. C., 16.
61.05	.166	Sölvbergite.....	Coney Island, Mass.....	J. G., VII, 118.—W. T.
60.33	.193	Trachyte.....	Monte Nuovo, Italy.....	A. J. S., VIII, 1899, 287.—W. T.
60.13	.165	Nephelite-syenite....	Fourche Mountain, Ark.....	J. G., IX, 610.—W. T.
60.02	.147	Syenite-keratophyre..	Harz Mountains.....	R. T., 1884, XXII.
59.79	.186	Trachyte.....	Monte Nuovo, Italy.....	A. J. S., VIII, 1899, 287.—W. T.
59.70	.164	Nephelite-syenite....	Fourche Mountain, Ark.....	I. R. A., 88.—W. T.
58.75	.176	Umptekite.....	Cabo Frio, Brazil.....	T. M. P. M., XX, 248.—W. T.
57.18	.171	Trachyte.....	Highwood Mountains, Mont.....	Bull. 168, 131.—W. T.

SUBRANG 4. NORDMARKOSE.

(I. 5, 1, 4.)

66.50	0.162	Lestliwarite.....	Kvella, Norway.....	E. K., III, 216.—W. T.
66.22	.149 (66.4)	Quartz-syenite - por- phyry.	Bearpaw Mountains, Mont.....	Bull. 168, 135.—W. T.
66.06	.151	Liparite.....	Hohenburg, near Bonn, Prussia.....	R. T., 1884, XLVIII.
65.51	.143	Phonolitic andesite..	San Mateo Mountains, N. Mex.....	Bull. 168, 170.—W. T.
65.43	.140 (65.1)	Nordmarkite.....	Shefford Mountain, Quebec.....	J. G., XI, 271.
64.92	.146	Quartz-sölvbergite....	Gran, Norway.....	E. K., I, 78.—W. T.
64.54	.157	Pulaskite.....	Lovaabucht, Norway.....	E. K., III, 198.—W. T.
64.33	.151	Acmite-trachyte.....	Crazy Mountains, Mont.....	Bull. 168, 123.—W. T.
63.76	.161 (63.4)	Syenite.....	Ahvenvaara, Finland.....	B. C. G. F., 11, 34.—W. T.
63.20	.161	Nordmarkite.....	Tonsenas, Norway.....	Z. K., XVI, 54.—W. T.
63.09	.164 (63.6)	Pulaskite.....	Salem Neck, Mass.....	J. G., VI, 806.—W. T.
62.17	.156	Acmite-trachyte.....	Crazy Mountains, Mont.....	Bull. 168, 123.—W. T.
61.67	.169	Keratophyre.....	Harz Mountains.....	R. T., 1884, XXII.
61.54	.180	Phonolite.....	Zittau, Saxony.....	R. T., 1861, 23.
61.08	.185	do.....	Black Hills, S. Dak.....	A. J. S., XLVII, 1894, 344.—W. T.
60.39	.184	Litchfieldite.....	Litchfield, Me.....	Bull. 168, 21.—W. T.
60.11	.161 (59.9)	Bostonite.....	Hedrum, Norway.....	E. K., III, 204.—W. T.
60.05	.157 (60.3)	Tingualite.....	Gales Point, Mass.....	J. G., VII, 481.—W. T.
59.62	.173	Nephelite-syenite....	Saline County, Ark.....	I. R. A., 135.—W. T.
59.31	.174	Foyalite.....	Great Haste Island, Mass.....	J. G., VII, 481.—W. T.

CHEMICAL COMPOSITION OF IGNEOUS ROCKS.

Classified list of analyses used in constructing diagrams—Continued.

SUBRANG 5. TUOLUMNOSE.

(I, 5, 1, 5.)

Silica con- tent.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
67.53	0.165	Albite.....	Tuolumne County, Cal.....	Bull. 168, 204.—W. T.
66.09	.162	do.....	Koswinsky, Ural Mountains.....	O. N., 169.

RANG 2. PULASKASE.

SUBRANG 2. VULSINOSE.

(I, 5, 2, 2.)

58.48	0.165	Leucite-trachyte(?)	Rocca Monfina, Italy.....	J. G., V, 370.—W. T.
58.21	.142	Vulsinite.....	Bolsena Monfina, Italy.....	J. G., V, 358.—W. T.
57.32	.156	do.....	Vetrella, Italy.....	Do.
55.17	.150	Leucite-trachyte.....	San Rocco, Italy.....	J. G., V, 370.—W. T.

SUBRANG 3. PULASKOSE.

(I, 5, 2, 3.)

65.54	0.135	Quartz-syenite.....	Highwood Mountains, Mont.....	W. T.
62.64	.119	Andesite (?).....	Pikes Peak district, Colo.....	Bull. 168, 145.—W. T.
61.87	.145	Trachyte.....	Ischia, Italy.....	R. T., 1873, XXXVIII.
61.55	.141	do.....	do.....	R. T., 1873, XXXVI.
60.89	.131	Quartz-basakite.....	Lshawood Canyon, Wyo.....	Bull. 168, 102.—W. T.
60.39	.165	Pulaskite.....	Fourche Mountain, Ark.....	J. G., IX, 608.—W. T.
60.08	.154	do.....	do.....	I. R. A., 88.—W. T.
59.51	.158	Leucite-trachyte.....	Viterbo, Italy.....	J. G., V, 370.—W. T.
59.23	.149	Nepheline-syenite.....	Fourche Mountain, Ark.....	I. R. A., 88.—W. T.
57.15	.149	Trachy-dolerite.....	Maros, Celebes.....	G. C., 14.
56.45	.175	Sodalite-syenite.....	Square Butte, Mont.....	Bull. 168, 134.—W. T.
55.52	.146	Bostonite.....	Gentungen, Celebes.....	G. C., 20.

SUBRANG 4. LAURVIKOSE.

(I, 5, 2, 4.)

65.41	0.139	Trachyte.....	Game Ridge, Custer County, Colo.....	Bull. 168, 147.—W. T.
64.90	.125	Domite.....	Puy de Dome, France.....	R. T., 1869, CXVIII.
64.68	.132	Quartz-syenite.....	Fourche Mountain, Ark.....	I. R. A., 96.—W. T.
63.49	.133	Andesite.....	Custer County, Colo.....	Bull. 168, 148.—W. T.
61.47	.120	do.....	Pantellaria, Italy.....	Z. K., VIII, 155.
61.43	.138	do.....	do.....	Z. K., VIII, 164.
61.05	.147	Trachyte.....	Ischia, Italy.....	R. T., 1873, XXXVIII.
60.98	.142 (59.9)	Augite-porphyrte.....	Henry Mountains, Utah.....	Bull. 168, 167.—W. T.
60.72	.143	Rhombenporphyry.....	Nötterö, Norway.....	Z. K., XVI, 35.—W. T.
60.45	.168	Nordmarkite.....	Aneröd, Norway.....	Z. K., XVI, 54.—W. T.
60.24	.170	Augite-andesite.....	Pantellaria.....	Z. K., VIII, 155.
59.96	.165	Pulaskite.....	Shefford Mountain, Quebec.....	J. G., XI, 271.
59.38	.126	Tönsbergite.....	Tönsberg, Norway.....	E. K., III, 375.—W. T.
58.94	.109	Andesite.....	Silver Cliff, Colo.....	Bull. 168, 148.—W. T.
58.88	.141	Laurvikite.....	Laurvik, Norway.....	Z. K., XVI, 39.—W. T.
58.82	.155	Rhombenporphyry.....	Tönsberg, Norway.....	Z. K., XVI, 35.—W. T.
57.59	.139	do.....	Nötterö, Norway.....	Do.
57.44	.137	Pulaskite.....	Mount Johnson, Quebec.....	J. G., XI, 271.

Classified list of analyses used in constructing diagrams—Continued.

SUBRANG 4. LAURVIKROSE—Continued.				
Silica con- tent.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
57.33	.153 (57.1)	Rhombenporphyry...	Nötterö, Norway	Z. K., XVI, 35.—W. T.
57.12	.138	Laurvikite	Fredriksvärn, Norway	Z. K., XVI, 30.—W. T.
56.85	.144	do	Nötterö, Norway	Do.
56.25	.155 (55.9)	Micromonzonite.....	Ambodimadiro, Madagascar	M. M., 204.
56.19	.156	Tephritic trachyte....	Columbretes Islands, Spain	T. M. P. M., XVI, 314.—W. T.
54.00	.162	Rhombenporphyry...	Brumunthal, Norway	Z. K., XVI, 28.—W. T.
SUBRANG 5. ———.				
(I. 5, 2, 5.)				
62.90	0.135	Diorite	Jablanica, Herzegovina	W. T.
60.13	.164	Kenatophyre.....	New Haven, Conn	A. J. S., III, 1897, 291.—W. T.
RANG 3. ———.				
SUBRANG 2. ———.				
(I. 5, 3, 2.)				
59.33	0.135 (59.5)	Augite-syenite.....	Mazaruni district, British Guiana	W. T.
SUBRANG 3. ———.				
(I. 5, 3, 3.)				
59.26	0.139	Andesite	Table Mountain, Colo.....	Bull. 168, 141.—W. T.
SUBRANG 4. ———.				
(I. 5, 3, 4.)				
58.28	0.112	Diabase-porphyrte...	Crazy Mountains, Mont	Bull. 168, 121.—W. T.
RANG 4. LABRADORASE.				
SUBRANG 3. LABRADOROSE.				
(I. 5, 4, 3.)				
55.01	0.086	Anorthosite	Turtschinka, Wolynien, Russia	W. T.
54.62	.093	do	New York State	N. J., 1893, VIII, 494.
54.45	.122	do	Rawdon, Canada	Do.
53.53	.090 (53.6)	do	Pökölä, Finland.....	W. T.
53.43	.099	do	Labrador, Canada	N. J., 1893, VIII, 494.—W. T.
53.42	.096	do	Ogne, Norway	B. M. A., 1896, V, 96.—W. T.
52.61	.092	do	Ekersund, Norway	B. M. A., 1896, V, 79.—W. T.
49.78	.091	do	Carlton Peak, Minn	Am. Geol., XXVI, 281.—W. T.
47.25	.056	do	Beaver Bay, Lake Superior.....	U. S. G. S., Mon. V, 438.
RANG 5. CANADASE.				
(I. 5, 5.)				
47.32	0.048 (47.4)	Anorthosite	South Sherbrooke, Ontario.....	Am. Geol., XXIV, 280.—W. T.
46.24	.044	do	Seine River, Canada.....	J. G., IV, 909.—W. T.
45.78	.036	do	Monhegan Isle, Me.....	Am. Geol., XXVI, 340.—W. T.

Classified list of analyses used in constructing diagrams—Continued.

ORDER 6. RUSSARE.

RANG 1. MIASKASE.

SUBRANG 3. BEEMEROSE.

(I. 6, 1, 3.)

Silica con- tent.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
60.42	0.184	Nephelite-syenite	Moita, Foya, Portugal	T. M. P. M., XVI, 225.—W. T.
59.20	.189 (59.1)	Microditroite	Nosy Komba, Madagascar	M. M., 169.
58.89	.180	Leucite-tinguaite- vitrophyre.	Picota, Portugal	T. M. P. M., XVI, 252.—W. T.
58.72	.199 (58.8—200)	Ditroite	Nosy Komba, Madagascar	M. M., 204.
58.00	.199	Phonolite	Maros, Celebes	G. C., 18.
55.87	.201 (55.3)	Leucite-phonolite	Lake Bracciano, Italy	J. G., V., 370.—W. T.
55.38	.207	Foyaite	East Cape, Siberia	A. J. S., XIII, 1902, 176.—W. T.
53.56	.229 (53.1)	Nephelite-syenite	Beemerville, N. J.	Bull. 168, 39.—W. T.
53.09	.226	Foyaite	Magnet Cove, Ark	J. G., IX, 611.—W. T.

SUBRANG 4. MIASKOSE.

(I. 6, 1, 4.)

60.02	0.202	Phonolite	Cripple Creek, Colo.	Bull. 168, 143.—W. T.
59.38	.189	Trachytic phonolite	do	Bull. 168, 144.—W. T.
59.00	.196	Phonolite	do	Bull. 168, 143.—W. T.
58.98	.219	do	do	Do.
58.78	.213	do	do	Do.
58.77	.211 (59.1)	Foyaite	Salem Neck, Mass.	J. G., VII, 481.—W. T.
58.74	.205	Nephelite-syenite	Salina County, Ark.	I. R. A., 139.—W. T.
58.70	.190	Acmite-trachyte	Crazy Mountains, Mont.	Bull. 168, 123.—W. T.
58.64	.196 (.196)	Phonolite	Cripple Creek, Colo.	Bull. 168, 143.—W. T.
58.62	.191 (58.5—184)	do	Nosy Komba, Madagascar	M. M., 169.
58.61	.194 (58.3)	Foyaite	Heum, Lougenthal, Norway	E. K., III, 377.—W. T.
58.61	.213 (58.5)	do	Nosy Komba, Madagascar	M. M., 169.
58.51	.216 (58.2)	Phonolite	Velay, France	R. T., 1879, LVIII.
58.25	.197 (57.7)	Microfoyaite	Nosy Komba, Madagascar	M. M., 169.
58.20	.190	Ditroite	do	Do.
58.10	.191 (57.9)	do	do	M. M., 204.
57.86	.214 (57.8)	Phonolite	Black Hills, S. Dak.	Bull. 168, 84.—W. T.
56.75	.228	Tinguaite	Pickards Point, Mass.	J. G., VII, 481.—W. T.
56.67	.226 (56.3)	Nephelite-syenite	Picota, Portugal	T. M. P. M., XVI, 228.—W. T.
56.43	.195 (56.3)	Phonolite	Hegau, Germany	R. T., 1884, LIV.
56.40	.201	Nephelite-syenite	Poutelitschorr, Kola, Finland	Rosenbusch, El., 126.—W. T.
56.30	.235	Ditroite	Ditro, Siebenbürgen, Hungary	Rosenbusch, El., 126.
56.26	.199 (56.8)	Miascite	Mount Sobatchia, Siberia	W. T.
55.95	.256	Phonolite	Borzen, Billn	R. T., 1869, XCVI.
55.98	.203 (55.6)	Trachytic phonolite	Columbretes Islands	T. M. P. M., XVI, 314.—W. T.
55.92	.198 (55.8)	Phonolite	Hegau, Germany	R. T., 1884, LII.
55.21	.226	do	do	R. T., 1879, LVIII.
55.01	.211	do	do	R. T., 1884, LII.
54.92	.243	Nephelite-aplite	Cabo Frio Island, Brazil	T. M. P. M., XX, 288.—W. T.
54.22	.224	Phonolite	Southboro, Mass.	Bull. 168, 33.—W. T.
54.20	.237	Nephelite-syenite	Picota, Portugal	T. M. P. M., XVI, 218.—W. T.
53.95	.246	Phonolite	Sardinia	R. T., 1879, LVIII.
53.65	.231	do	Msid Gharlan, Tripoli	R. T., 1884, LIV.
52.73	.202	Heronite	Heron Bay, Canada	J. G., VII, 435.—W. T.

SUBRANG 5. MARIUPOLOSE.

(I. 6, 1, 5.)

Silica con- tent.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
60.29	0.197 (60.5)	Mariupolite	Nikolajew, Russia.....	T. M. P. M., XXI, 244.—W. T.

RANG 2. VIEZZENASE.

SUBRANG 3. —.

(I. 6, 2, 3.)

53.76	0.207 (53.6)	Nephelite-tinguaite ..	Magnet Cove, Ark.....	I. R. A., 266.—W. T.
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SUBRANG 4. VIEZZENOSE.

(I. 6, 2, 4.)

56.04	0.201	Nephelite-rhomben- porphyry.	Vasvik tunnel, Norway	Z. K., XVI, 38.—W. T.
55.40	.184	Andesite	Palma, Sicily.....	R. T., 1879, LXVI.
54.68	.176	Nephelite-syenite	Brookville, N. J.....	Bull. 168, 39.—W. T.
54.61	.197	do	Caldas de Monchique, Portugal.....	N. J., B. B., III, 271.—W. T.
54.46	.186	Tinguaite	Umptek, Kola, Finland	Rosenbusch, El., 215.—W. T.

ORDER 7. TASMANARE.

RANG 1. LAUGENASE.

SUBRANG 4. LAUGENOSE.

(I. 7, 1, 4.)

55.50	0.248	Foyaite.....	Brathagen, Norway	E. K., III, 176.—W. T.
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CLASS II. DOSALANE.

ORDER 3. HISPANARE.

RANG 1. VARINGASE.

SUBRANG 3. VARINGOSE.

(II. 3, 1, 3.)

74.35	0.092	Grorudite	Varingskollen, Norway	Z. K., XVI, 66.—W. T.
70.30	.128	Pantellerite	Pantellaria.....	Z. K., VIII, 173.—W. T.

SUBRANG 4. —.

(II. 3, 1, 4.)

72.12	0.070	Felsite.....	Cudgegong River, New South Wales, Australia.	W. T.
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Classified list of analyses used in constructing diagrams—Continued.

RANG 4. ———.

SUBRANG 3. ———.

(II. 3, 4, 3.)

Silica con- tent.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
66.88	0.020	Quartz-diorite	Little Falls, Minn	R. T., 1879, XXXVI.

ORDER 4. AUSTRALIA.

RANG 1. PANTELLERASE.

SUBRANG 3. GRORUDOSE.

(II. 4, 1, 3.)

70.15	0.109	Grorudite	Grussletten, Norway	E. K., I, 199.—W. T.
69.61	.129	Pantellerite	Pantellaria	Z. K., VIII, 173.—W. T.
69.02	.121	do	do	Z. K., VIII, 182.—W. T.
68.33	.137	do	do	Z. K., VIII, 170.—W. T.
66.50	.123	Grorudite	Grussletten, Norway	E. K., I, 199.—W. T.
61.88	.102 (62.2)	Porphyrite	Süpplingen, Magdeburg, Prussia.....	W. T.

SUBRANG 4. PANTELLEROSE.

(II. 4, 1, 4.)

71.35	0.116	Grorudite	Kallerud, Norway.....	E. K., I, 199.—W. T.
67.89	.116	Pantellerite	Pantellaria	Z. K., VIII, 186.—W. T.
67.48	.131	do	do	Do.
67.18	.122	do	do	Do.

RANG 2. DACASE.

SUBRANG 3. ADAMELLOSE.

(II. 4, 2, 3.)

66.57	0.108	Granite-porphry	Kirche Wang, Silesia.....	Rosenbusch, El., 195.
63.97	.105	Quartz-mica-diorite ..	Crandall Basin, Wyo	Bull. 168, 94.—W. T.
62.51	.090	Syenite	Reichenstein, Silesia	N. J., 1890, I, 206.—W. T.
61.98	.104	Granitite	Laveline, Vosges	Rosenbusch, El., 78.
59.24	.095 (59.5)	Trachyte-andesite.....	Highwood Mountains, Mont.....	Bull. 168, 131.—W. T.

SUBRANG 4. DACOSE.

(II. 4, 2, 4.)

63.50	0.107	Andesite	Sepulchre Mountain, Yellowstone Park.	Bull. 168, 91.—W. T.
63.17	.098	Granitite	Crazy Mountains, Mont	Bull. 168, 120.—W. T.
63.00	.101	Dacite	Chiles, Colombia, South America	J. G., I, 171.—W. T.
61.00	.102	Andesite	Tower Creek, Yellowstone Park	Bull. 168, 108.—W. T.
60.00	.083	Quartz-diorite	Sauk Center, Minn.....	R. T., 1879, XXXIV.

Classified list of analyses used in constructing diagrams—Continued.

RANG 3. TONALASE.

SUBRANG 3. HARZOSE.

(II. 4, 3, 3.)

Silica con- tent.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
64.34	0.081	Granite.....	Butte, Mont.....	Bull. 168, 117.—W. T.
63.85	.080	Granodiorite.....	Grass Valley, Cal.....	Bull. 168, 194.—W. T.
63.06	.069 (63.2)	"Schliere" in granite.....	Riesengebirge, Silesia.....	N. J., 1898, XII, 236.—W. T.
61.73	.088	Syenite.....	Hodritsch, Hungary.....	R. T., 1869, LX.
61.64	.078	Quartz-monzonite.....	Red Rock Creek, Butte, Mont.....	Bull. 168, 118.—W. T.
60.68	.090 (60.7)	Andesite.....	Mount Pagos, Asia Minor.....	A. J. S. III, 1897, 43.—W. T.
60.17	.090	Latite.....	Tintic district, Utah.....	Bull. 168, 166.—W. T.
59.76	.094	Monzonite.....	do.....	Do.
57.80	.063	Quartz-pyroxene-dio- rite.....	Sonora, Tuolumne County, Cal.....	Bull. 168, 204.—W. T.
57.69	.064 (58.1)	Mica-diorite.....	Gippeland, Victoria.....	E. K., II, 37.—W. T.
57.26	.076	Quartz-mica-diorite.....	Sierra County, Cal.....	Bull. 168, 192.—W. T.

SUBRANG 4. TONALOSE.

(II. 4, 3, 4.)

66.91	0.055	Tonalite.....	Adamello Stock, Tyrol.....	Rosenbusch, El., 140.—W. T.
65.83	.080	Granite.....	Granite Creek Station, Nev.....	Fortieth Par., I, 110.
65.39	.081	Dacite.....	Cumbal, Colombia, South America.....	J. G., I, 171.—W. T.
65.11	.083	Quartz-mica-diorite.....	Electric Peak, Yellowstone Park.....	Bull. 168, 88.—W. T.
64.81	.073	Porphyrite.....	Leadville district, Colo.....	Bull. 168, 155.—W. T.
64.12	.077 (.076)	Quartz-norite.....	Tyrol.....	Rosenbusch, El., 140.
64.07	.083	Quartz-mica-diorite.....	Electric Peak, Yellowstone Park.....	Bull. 168, 87.—W. T.
63.56	.084	Hornblende-dacite.....	Colombia, South America.....	J. G., I, 171.—W. T.
63.47	.075	Andesite.....	Suppans Mountain, Tehama County, Cal.,	Bull. 168, 182.—W. T.
63.28	.077	do.....	Mount Hood, Oreg.....	Fortieth Par., I, 604.
63.16	.089	Trachyte.....	Henry Mountains, Utah.....	Bull. 168, 167.—W. T.
63.03	.070	Andesite.....	Mount Shasta, Cal.....	Bull. 168, 176.—W. T.
62.71	.084	Diorite.....	Gunnison County, Colo.....	Bull. 168, 159.—W. T.
62.65	.095	Hornblende-porphy- rite.....	Herman Peak, Colo.....	Bull. 168, 164.—W. T.
62.62	.070	Quartz-mica-diorite.....	Mariposa County, Cal.....	Bull. 168, 209.—W. T.
62.44	.071	Andesite.....	Shasta County, Cal.....	Bull. 168, 181.—W. T.
62.09	.070	Hornblende-porphy- rite.....	Nevada City, Cal.....	Bull. 168, 194.—W. T.
61.58	.074 (61.8)	Andesite.....	Mount Shasta, Cal.....	Bull. 168, 176.—W. T.
61.40	.048	Syenite.....	Riesengebirge, Silesia.....	N. J., 1898, XII, 234.—W. T.
61.22	.089 (61.4)	Mica-diorite.....	Electric Peak, Yellowstone Park.....	Bull. 168, 87.—W. T.
61.17	.077	Andesite.....	Shasta County, Cal.....	Bull. 168, 183.—W. T.
61.16	.093	Andesite-porphry.....	Crandall Basin, Wyo.....	Bull. 168, 94.—W. T.
61.09	.070	Andesite.....	Colombia, South America.....	J. G., I, 171.—W. T.
61.04	.090	do.....	do.....	Do.
60.93	.073	do.....	Tuscan Buttes, Cal.....	Bull. 168, 181.—W. T.
60.30	.088 (60.4)	do.....	Sepulchre Mountain, Yellowstone Park.	Bull. 168, 90.—W. T.
60.20	.068	do.....	Pilot Peak, Plumas County, Cal.....	Bull. 168, 188.—W. T.
60.05	.079	do.....	Colombia, South America.....	J. G., I, 171.—W. T.
60.04	.078 (60.3)	do.....	Shasta County, Cal.....	Bull. 168, 181.—W. T.
60.02	.074 (59.8)	do.....	Sierra County, Cal.....	Bull. 168, 193.—W. T.

CHEMICAL COMPOSITION OF IGNEOUS ROCKS.

Classified list of analyses used in constructing diagrams—Continued.

SUBRANG 4. TONALITE—Continued.

Silica con- tent.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
59.97	.076	Diorite	Völkartthal, Tyrol.....	Rosenbusch, EL., 140.
59.84	.090	Andesite	Near Lassen Peak, Cal	Bull. 168, 183.—W. T.
59.77	.090	Average of 690 igne- ous rocks.	America.....	Bull. 168, 12.—W. T.
59.48	.092	Andesite	Red Bluff, Mont.....	Bull. 168, 114.—W. T.
59.34	.075	do	Sierra County, Cal.....	Bull. 168, 193.—W. T.
59.19	.094	Diorite	San Miguel Mountains, Colo	Bull. 168, 164.—W. T.
59.67	.065	Dolerite	Eskdale, Scotland	
59.63	.079 (59.9)	Diorite	Unalaska Island.....	Bull. 168, 226.—W. T.
59.46	.093 (59.7)	Average of 297 igne- ous rocks.	Great Britain.....	Geol. Mag., 1899, 220.—W. T.
59.09	.075 (58.2)	Andesite	Near Lassen Peak, Tehama County, Cal.	Bull. 168, 182.—W. T.
58.61	.092	do	Sepulchre Mountain, Yellowstone Park.	Bull. 168, 90.—W. T.
58.28	.066	Diorite	Electric Peak, Yellowstone Park.....	Bull. 168, 87.—W. T.
58.92	.069 (58.9)	Andesite	Sepulchre Mountain, Yellowstone Park.	Bull. 168, 90.—W. T.

SUBRANG 5. PLACEROSE.

(II. 4, 3, 5.)

64.67	0.064	Granite.....	Placer County, Cal	Bull. 168, 198.—W. T.
60.40	.068	Andesite	St. Augustine Volcano, Cook Inlet...	Bull. 168, 226.—W. T.

RANG 4. BANDASE.

SUBRANG 1. SAGANOSE.

(II. 4, 4, 1.)

56.48	0.023	Tonalite	Hokizawa, Sagami, Japan.....	W. T.
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SUBRANG 3. BANDOSE.

(II. 4, 4, 3.)

61.59	0.067	Diorite	Kadiak Island, Alaska	Bull. 168, 227.—W. T.
59.66	.062	Andesite	Bandai San, Japan	W. T.
58.74	.047	Diabase-porphry	Mount Morrison, Colo.....	Bull. 168, 141.—W. T.
58.51	.068 (58.7—.066)	Quartz-basalt.....	Near Lassen Peak, Cal	Bull. 168, 185.—W. T.
58.41	.062	Diorite	Georgetown, D. C.....	Bull. 168, 44.—W. T.
58.31	.044	"Schlieren" in granite	Riesengebirge, Silesia.....	N. J., 1898, XII, 235.—W. T.
58.97	.062	Diorite	Triadelphia, Md.....	Bull. 168, 44.—W. T.

RANG 5. ———.

SUBRANG 3. ———.

(II. 4, 5, 3.)

61.62	0.015	Diorite	Kagelholmsön, Sweden	R. T., 1879, XXXII.
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ORDER 5. GERMANARE.

RANG 1. UMPTEKASE.

SUBRANG 2. HIGHWOODOSE.
(II. 5, 1, 2.)

Silica con- tent.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
61.28	0.125	Syenite	Tuolumne County, Cal	Bull. 168, 204.—W. T.
58.04	.166	Trachyte	Highwood Mountains, Mont	Bull. 168, 131.—W. T.

SUBRANG 3. ILMENOSE.
(II. 5, 1, 3.)

62.99	0.139	Umptekite	Beverly, Mass	T. M. P. M., XX, 248.—W. T.
57.91	.181	Sodalite-trachyte	Monte Santo, Naples, Italy	A. J. S., VIII, 1899, 290.—W. T.
55.26	.171	Leucite-trachyte	Viterbo, Italy	J. G., V, 370.—W. T.

SUBRANG 4. UMPTEKORE.
(II. 5, 1, 4.)

64.28	0.156	Sölvbergite	Andrews Point, Mass	J. G., VII, 481.—W. T.
63.71	.152	Umptekite	Kola, Finland	Rosenbusch, El., 112.—W. T.
62.70	.162	Sölvbergite	Laugendal, Norway	E. K., I, 199.—W. T.
60.50	.159	Hedrumite	Ostø, Norway	E. K., III, 377.—W. T.
59.66	.180	Nephelite-syenite	Crazy Mountains, Mont	Bull. 168, 123.—W. T.
59.01	.171	do	Red Hill, N. H	Bull. 168, 23.—W. T.
58.90	.181	Nephelite-sölvberg- ite.	Aklungen, Norway	E. K., I, 199.—W. T.
58.81	.163	Soda-syenite	Laupstadeid, Norway	B. M. A., 1898, VII, 48.—W. T.
58.46	.162	Nordmarkite	Cabo Frio, Brazil	T. M. P. M., XX, 244.—W. T.
57.52	.172	Hedrumite	Brathagan, Norway	E. K., III, 190.—W. T.
57.00	.170	Heumite	do	E. K., III, 116.—W. T.

RANG 2. MONZONASE.

SUBRANG 2. CIMINOSE.
(II. 5, 2, 2.)

56.39	0.110 (56.6)	Mica-trachyte	Monte Catini, Italy	A. J. S., IX, 1900, 47.—W. T.
55.85	.157	Leucite-phonolite	Bolsena, Italy	J. G., V, 370.—W. T.
55.46	.107	Ciminite	Monte Cimino, Italy	A. J. S., IX, 1900, 44.—W. T.
55.21	.151	Leucite-trachyte	Viterbo, Italy	J. G., V, 370.—W. T.
51.05	.125	Durbachite	Schwarzwald, Baden	W. T.

SUBRANG 3. MONZONOSE.
(II. 5, 2, 3.)

61.65	0.113	Syenite	Yogo Peak, Little Belt Mountains, Mont.	Bull. 168, 125.—W. T.
60.56	.127	Granite	Elliott County, Ky	Bull. 168, 56.—W. T.
59.78	.140	Syenite	Custer County, Colo	Bull. 168, 151.—W. T.
58.18	.134	Kersantite	Tito, Chile	Z. D. G. G., LI, 4.—W. T.

CHEMICAL COMPOSITION OF BASIC ROCKS.

Classification list of analyses used in constructing Diagrams 4, 5, and 6.

TABLE NO. 1. MONZONITES—Continued.

Alkali con- tent.	Alkali-alkali ratio.	Author's name.	Locality.	Reference.
61. 8	1.52	Granite	Langenthal, Norway.	Z. K., III, 375.—W. T.
61. 47	1.16	Diorite	Mount Asensio, Vermont.	Bull. 188, 25.—W. T.
61. 73	1.57	Granite	Belma, Italy.	A. T., 1871, XXXVIII.
61. 46	1.18	Andesite	Placer Point District, Calif.	Bull. 188, 145.—W. T.
61. 29	1.24	Quartz-monzonite	Head of Lemay River, Wyo.	Bull. 188, 162.—W. T.
61. 75	1.46	Granite	Asso, Belma, Italy.	A. T., 1871, 1898, 286.—W. T.
61. 25	1.10	Mica-monzonite	Santa Maria Basin, Arizona.	Bull. 188, 171.—W. T.
61. 23	1.45	Granite	Highwood Mountains, Mont.	Bull. 188, 111.—W. T.
61. 46	1.14	Shoshonite	Indian Point, Wyo.	Bull. 188, 186.—W. T.
61. 62	1.16 64. 0	Monzonite	Topo Peak, Mont.	Bull. 188, 128.—W. T.
61. 23	1.10	do	Monzon, Tenn.	Z. K., II, 14.—W. T.
61. 41	1.24 72. 5	do	Sawpaw Mountains, Mont.	Bull. 188, 125.—W. T.
61. 40	1.10	Granite-monzonite	Marva, Colorado.	G. C., 25.
61. 23	1.12	Granite	Shoshone Mountain, Wyo.	Bull. 188, 111.—W. T.
61. 23	1.12	do	Head of Lemay River, Wyo.	Do.
61. 14	1.16	Granite	Hessenberg, Baden.	A. T., 1871, XXXV.
61. 23	1.14	Granite	Head of Lamar River, Yellowstone Park.	Bull. 188, 111.—W. T.
61. 46	1.11	do	Lemay River, Wyo.	Do.

TABLE NO. 2. ANDESITES.

II. 1, 2, 3, 4.

61. 57	1.129	Granite	Castle Mountain District, Mont.	Bull. 188, 138.—W. T.
61. 62	1.25	Nephelinite-granite	Monarto, Tenn.	Z. K., V, 10, 1871, 189.
61. 26	1.04	Andesite	Columbia, South America.	A. T., I, 171.—W. T.
61. 28	1.14	Porphyrite	Crater Mountains, Mont.	Bull. 188, 129.—W. T.
61. 44	1.10	Diorite-porphyr	La Plata Mountains, Colo.	Bull. 188, 162.—W. T.
61. 4	1.25	Andesite	Vestmålén, Norway.	Z. K., XVI, 90.—W. T.
61. 28	1.10	Granite	Crater Mountains, Mont.	Bull. 188, 121.—W. T.
61. 11	1.24	Andesite	Silver Cliff, Colo.	Bull. 188, 145.—W. T.
61. 79	1.16	Andesite	Vestmålén, Norway.	Z. K., XVI, 90.—W. T.
61. 75	1.16	Porphyrite	Crater Mountains, Mont.	Bull. 188, 121.—W. T.
61. 62	1.10	Andesite	Peak, Luzon, P. I.	N. J., B. B., I, 1881, 482.
61. 65	1.15	Diorite	Noré, Kombo, Madagascar.	M. M., 394.
61. 23	1.10	Diorite	La Plata Mountains, Colo.	Bull. 188, 162.—W. T.
61. 49	1.16 64. 5	Porphyrite	Crater Mountains, Mont.	Bull. 188, 121.—W. T.
61. 40	1.14	Diorite	Silver Cliff, Colo.	Bull. 188, 145.—W. T.
61. 40	1.24	Basalt	Bannhardswand, Prussia.	W. T.
61. 16	1.12	Basalt	Shoshone Mountain, Idaho.	A. T., XI, 355.
61. 12	1.12	Porphyrite-trachyte	Columbrete Islands.	P. M., 1871, 189, 184.—W. T.
61. 62	1.16 61. 8	Basalt	S. Rhone.	A. T., 1871, XXXII.
61. 22	1.12	Minette	Brathagen, Norway.	Z. K., III, 375.—W. T.

TABLE NO. 3. ANDESITES.

I. 1, 2, 3, 4.

II. 1, 2, 3, 4.

61. 11	1.104	Granite	Monte Cimino, Italy.	A. T., 1871, 189, 184.—W. T.
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ROCK ANALYSES USED IN CONSTRUCTING DIAGRAMS.

Classified list of analyses used in constructing diagrams—Continued.

SUBBRANG 3. SHOSHONITE.
(II. 5, 3, 3.)

silica cont.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
59.41	0.102	Andesite	Cabo da Gata, Spain.....	Z. D., g. G., XLIII, 719.—W. T.
58.51	.085 (58.8)	Mica-diorite.....	Crystals Falls, Mich.....	Bull. 168, 67.—W. T.
57.97	.083 (57.8)	Diorite	Crazy Mountains, Mont	Bull. 168, 122.—W. T.
56.90	.097	Syenite	Denver Basin, Colo.....	Bull. 168, 140.—W. T.
56.78	.093	Latite	Clover Meadow, Cal.....	Bull. 168, 205.—W. T.
56.19	.092	do	Table Mountain, Tuolumne County, Cal.	Bull. 168, 205.—W. T.
56.06	.107	Shoshonite	Two Ocean Pass, Yellowstone Park..	Bull. 168, 100.—W. T.
55.69	.100 (55.6)	Vulsinite	Rocca Monfina, Italy.....	J. G., V, 358.—W. T.
54.56	.076 (.075)	Andesite	Radicefani, Italy.....	A. J. S., IX, 1900, 52.—W. T.
64.14	.077	do	do	Do.
53.49	.104	Shoshonite	Beaverdam Creek, Yellowstone Park.	Bull. 168, 100.—W. T.
52.93	.132	Banakitite	do	Bull. 168, 102.—W. T.
52.59	.099 (52.7)	Basalt	Table Mountain, Colo.....	Bull. 168, 140.—W. T.
52.49	.102	Shoshonite	Pyramid Peak, Yellowstone Park....	Bull. 168, 100.—W. T.
52.33	.103	Augite-porphyy	Cottonwood Creek, Mont.....	Bull. 168, 112.—W. T.
52.11	.097 (51.8)	Basalt	Crandall Basin, Wyo.....	Bull. 168, 92.—W. T.
51.00	.115	Monzonite.....	Highwood Mountains, Mont	Bull. 168, 133.—W. T.
50.98	.120 (50.7)	Mondhaldeite	Mondhalde, Kaiserstuhl, Baden	W. T.
50.08	.137	do	do	Do.
50.06	.110	Shoshonite	Lamar River, Yellowstone Park	Bull. 168, 100.—W. T.
49.69	.107	Basalt	Denver Basin, Colo.....	Bull. 168, 140.—W. T.
48.25	.118	Dolerite	do	Do.
47.50	.117	Labrador-porphyrite	Gran, Norway	Q. J. G. S., L, 33.—W. T.
45.53	.140	Leucite-monzonite	Bohemian Mittelgebirge	Rosenbusch, El., 235.—W. T.

SUBBRANG 4. ANDESITE.
(II. 5, 3, 4.)

58.45	0.080	Diorite	Pen Maen Mawr, N. Wales.....	Q. J. G. S., XXXIII, 424.
58.42	.099	Andesite	Taal, Luzon, P. I.....	N. J., B. B., I, 1881, 481.
58.05	.083	Diorite	Electric Peak, Yellowstone Park.....	Bull. 168, 87.—W. T.
57.64	.104 (57.8)	Augite-porphyrite	Crandall Basin, Wyo	Bull. 168, 93.—W. T.
57.59	.070 (57.8)	Quartz-basalt.....	Silver Lake, Lassen, Cal	Bull. 168, 185.—W. T.
57.38	.071 (57.1)	Pyroxene porphyry ..	Electric Peak, Yellowstone Park.....	Bull. 168, 87.—W. T.
57.32	.098 (57.5)	Monzonite.....	Crandall Basin, Wyo	Bull. 168, 93.—W. T.
57.26	.102	Diorite	do	Do.
57.25	.067	Quartz-basalt.....	Cinder Cone, Lassen, Cal.....	Bull. 168, 184.—W. T.
57.17	.079	Andesite.....	Sepulchre Mountain, Yellowstone Park.	Bull. 168, 90.—W. T.
57.11	.084 (57.5)	do	Mill Creek, Lassen, Cal.....	Bull. 168, 182.—W. T.
56.91	.085	do	Colombia, South America	J. G., I, 171.—W. T.
56.70	.074 (56.6)	Quartz-basalt.....	Cinder Cone, Lassen, Cal	J. G., I, 184.—W. T.
56.49	.112 (57.1)	Diorite	Little Falls, Minn	R. T., 1879, XXXIV.
56.21	.104	Gabbro-diorite.....	Crandall Basin, Wyo	Bull. 168, 93.—W. T.
56.19	.076	Andesite	Buffalo Peaks, Colo.....	Bull. 168, 153.—W. T.
56.09	.090	Diorite	Campo Major, Portugal	E. K., II, 37.—W. T.
56.07	.091 (56.9)	Andesite	Bogoslof Island	Bull. 168, 227.—W. T.
55.93	.103 (56.8)	Gabbro-diorite	Crandall Basin, Wyo	Bull. 168, 93.—W. T.
55.92	.095	Andesite	Sepulchre Mountain, Yellowstone Park.	Bull. 168, 90.—W. T.
55.80	.076	Diorite (norite)	Klausen, Tyrol	E. K., II, 37.—W. T.
55.34	.093	Norite	Montrose Point, N. Y.....	W. T.

CHEMICAL COMPOSITION OF IGNEOUS ROCKS.

Classified list of analyses used in constructing diagrams—Continued.

SUBRANG 4. ANDOSE—Continued.

Silica con- tent.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
55.20	0.075 (55.4)	Andesite	Butte County, Cal	Bull. 168, 182.—W. T.
55.13	.107	Diorite	Neihart, Mont	Bull. 168, 127.—W. T.
54.62	.075	Andesite	Luzon, P. I.	N. J., B. B., I, 1881, 471.
54.56	.108	Diorite-porphyrte...	Crazy Mountains, Mont	Bull. 168, 121.—W. T.
54.52	.092	Diabase	Diabase Hills, Nev.....	Fortieth Par., II, 812.
53.94	.086	Dolerite	do	Do.
53.89	.099	Basic andesitic glass..	Indian Ridge, Wyo	Bull. 168, 92.—W. T.
53.71	.098	Mica-gabbro.....	Crandall Basin, Wyo	Do.
53.48	.089	Quartz-diorite	Crazy Mountains, Mont	Bull. 168, 121.—W. T.
53.10	.134 (53.2)	Covite	Nosey Komba, Madagascar.....	M. M., 204.
52.97	.107	Basalt	Pikes Peak district, Colo	Bull. 168, 145.—W. T.
52.91	.119	Diabase-syenite-por- phyry.	Holmestrand, Norway	Z. K., XVI, 28.—W. T.
52.63	.082 (52.7)	Basalt	Shasta County, Cal	Bull. 168, 186.—W. T.
52.38	.093	do	Rio Grande, N. Mex	Bull. 168, 169.—W. T.
52.37	.084	do	Absaroka Range, Yellowstone Park..	Bull. 168, 109.—W. T.
52.37	.082 (51.8)	do	Rio Grande, N. Mex	Bull. 168, 169.—W. T.
52.27	.095	do	do	Do.
52.12	.095	Diorite	Mount Ascutey, Vt.....	Bull. 168, 25.—W. T.
52.09	.085	Basalt	Crandall Basin, Wyo	Bull. 168, 92.—W. T.
51.57	.090	do	Rio Grande, N. Mex	Bull. 168, 169.—W. T.
51.54	.110	Andesite	Bogoslof Island, Alaska	Bull. 168, 227.—W. T.
50.99	.101	Camptonite	Ishawooc Canyon, Wyo	Bull. 168, 110.—W. T.
50.97	.112 (50.6)	Kersantite.....	Guanta, Chile	Z. D. g. G., LI, 4.
50.73	.099	Diorite	Crazy Mountains, Mont	Bull. 168, 122.—W. T.
50.56	.079	Basalt	Plumas County, Cal	Bull. 163, 189.—W. T.
49.40	.087	Facies of monzonite..	Predazzo, Tyrol	E. K., II, 102.—W. T.
49.24	.092 (49.7)	Dolerite	Ferdinanda	T. M. P. M., 1883, 393.
49.04	.110	Basalt	Buffalo Peak, Colo	Fortieth Par., I, 676.
48.90	.090	Diorite	Schwarzenberg, Voeges.....	Rosenbusch, El., 140.
48.85	.131	Essexite	Mount Johnson, Quebec.....	J. G., XI, 265.
48.76	.105	Basalt	Pikes Peak district, Colo	Bull. 168, 145.—W. T.
48.18	.093	Olivine-diabase	Biella, Piedmont	R. T., 1884, XLII.
48.06	.084	Kersantite.....	Laugendal, Norway	E. K., III, 376.—W. T.
44.85	.110	Nephelite-tephrite ...	Mittelgebirge, Bohemia	Rosenbusch, El., 346.—W. T.

SUBRANG 5. BEERBACHOSE.

(II. 5, 3, 5.)

55.08	0.081	Andesite-basalt.....	Shasta County, Cal	Bull. 168, 176.—W. T.
52.58	.073	Andesite	S. W. Tiflis.....	Z. D. g. G., XXIX, 823.
47.21	.109	Beerbachite	Odenwald, Hesse.....	Rosenbusch, El., 219.—W. T.

RANG 4. HESSASE.

SUBRANG 3. HESSOSE.

(II. 5, 4, 3.)

57.47	0.072	Basalt	Cascade Range, Oreg.....	Bull. 168, 223.—W. T.
56.94	.074	Anorthosite	Elizabethtown, N. Y	Bull. 168, 37.—W. T.
55.53	.062	Andesite	Plumas County, Cal	Bull. 168, 181.—W. T.
55.14	.075	Secretion in dacite...	Lassen Peak, Cal	Bull. 168, 179.—W. T.

Classified list of analyses used in constructing diagrams—Continued.

RANG 4. HESSASE—Continued.

SUBRANG 3. HESSASE—Continued.

Silica con- tent.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
53.91	0.066	Dolerite	Plumas County, Cal.....	Bull. 168, 189.—W. T.
53.35	.063	Secretion in dacite...	Lassen Peak, Cal.....	Bull. 168, 180.—W. T.
53.18	.082	Anorthosite.	Whiteface Mountain, Adirondacks, N. Y.	Bull. 168, 36.—W. T.
53.00	.070	Diorite	Schwarzenburg, Vosges	Rosenbusch, El., 140.
52.95	.073 (52.7)	Basalt	Shasta County, Cal.....	Bull. 168, 186.—W. T.
52.16	.074	Monzonite.....	Predazzo, Tyrol	E. K., II, 25.—W. T.
52.05	.075 (51.7)	Diorite.....	Ouray County, Colo	Bull. 168, 161.—W. T.
51.27	.064	do	Little Falls, Minn	R. T., 1879, XXXIV.
49.93	.074	Dolerite	Paterno, Etna, Sicily.....	R. T., 1884, LXXX.
49.88	.057	Olivine-gabbro	Pigeon Point, Minn	Bull. 168, 76.—W. T.
49.80	.049	Gabbro	Crystal Falls, Mich.....	Bull. 168, 67.—W. T.
49.15	.095	do	Duluth, Minn	Rosenbusch, El., 151.
48.29	.039	Gabbro-diorite	Minnesota Falls, Minn.....	Bull. 168, 83.—W. T.
47.94	.060 (47.5)	Basalt	Shasta County, Cal	Bull. 168, 176.—W. T.
47.88	.065	Gabbro	Elizabethtown, N. Y.....	Bull. 168, 37.—W. T.
46.71	.036	Olivine-gabbro	Langenlois, Austria	R. T., 1879, XXXVIII.
46.45	.047	do	Minnesota	Bull. 168, 82.—W. T.
45.20	.071	Diorite	Tuc d'Ess, Pyrenees.....	C. G. I., VIII, 1901, 832.—W. T.
44.72	.047	Corsite	Poudière, Auvergne.....	R. T., 1879, XXXVI.
43.42	.044	Gabbro-diorite.....	Ilchester, Md.....	Bull. 168, 44.—W. T.
43.19	.094	Basalt	Westphalia	R. T., 1879, LXXIV.

RANG 5. CORSASE.

(II. 5, 5.)

44.04	0.027	Diorite	Stone Run, Md	Bull. 168, 45.—W. T.
43.41	.020	Olivine-gabbro	Tuolumne County, Cal.....	Bull. 168, 206.—W. T.

ORDER 6. NORGARE.

RANG 1. LAURDALASE.

SUBRANG 2. FERGUSOSE.

(II. 6, 1, 2.)

51.75	0.147	Pseudoleucite-syenite	Highwood Mountains, Mont.....	Bull. 168, 133.—W. T.
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SUBRANG 3. JUDITHOSE.

(II. 6, 1, 3.)

57.63	0.198	Tingualite	Judith Mountains, Mont.....	A. J. S., II, 1896, 192.—W. T.
57.46	.196 (57.3)	do	Bearpaw Mountains, Mont.....	Bull. 168, 136.—W. T.
53.09	.226 (53.2)	Foyalite.....	Magnet Cove, Ark.....	J. G., IX, 611.—W. T.
52.91	.224	Leucite-tingualite	do	I. R. A., 287.—W. T.
51.94	.157	Trachyte	Highwood Mountains, Mont.....	Bull. 168, 131.—W. T.

Classified list of analyses used in constructing diagrams—Continued.

SUBRANG 4. LAURDALOSE.

(II. 6, 1, 4.)

Silica con- tent.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
59.88	C. 188	Hedrumite	Hedrum, Norway	E. K., III, 377.—W. T.
56.58	.242	Tingualite	do	E. K., I, 199.—W. T.
56.35	.211	Laurdalite	Farris, Norway	E. K., III, 375.—W. T.
55.90	.209	Tingualite	Foya, Portugal	T. M. P. M., XVI, 262.—W. T.
55.65	.225	do	Hedrum, Norway	E. K., I, 199.—W. T.
55.18	.182	Syenite	do	E. K., III, 375.—W. T.
54.55	.192	Laurdalite	Lougendal, Norway	Do.
54.04	.233	Leucite-tingualite	Magnet Cove, Ark	I. R. A., 287.—W. T.
53.81	.192	Syenite-pegmatite	Stoksund, Norway	Z. K., XVI, 116.—W. T.
53.73	.214	Nephelite-syenite	Transvaal	Rosenbusch, El., 126.—W. T.
51.95	.155 (51.6)	Soda-minette	Langesundsfjord, Norway	E. K., II, 376.—W. T.
50.96	.229	Leucite-nephelite- syenite.	Magnet Cove, Ark	I. R. A., 276.—W. T.
47.61	.190	Tingualite	Two Buttes, Colo	Bull. 168, 165.—W. T.
45.16	.196	Olivine-laurdalite	Farris, Norway	E. K., III, 375.—W. T.

RANG 2. ESSEXASE.

SUBRANG 3. BOROLANOSE.

(II. 6, 2, 3.)

52.05	0.132	Monzonite	Highwood Mountains, Mont	Bull. 168, 133.—W. T.
51.35	.165	Nephelite-felsite	Magnet Cove, Ark	I. R. A., 283.—W. T.
50.24	.153 (49.9-154)	Leucite-tephrite	Bolsena, Italy	J. G., IV, 561.—W. T.
50.15	.142 (49.8)	Shonkinite	Maros, Celebes	G. C., 24.
49.70	.167	Covite	Magnet Cove, Ark	J. G., IX, 612.—W. T.
47.8	.204	Borolanite	Lake Borolan, Scotland	Rosenbusch, El., 126.—W. T.

SUBRANG 4. ESSEXOSE.

(II. 6, 2, 4.)

55.07	0.162	Rhombenporphyry	Stoksund, Norway	Z. K., XVI, 116.—W. T.
54.34	.173	Nephelite-syenite	Cripple Creek, Colo	Bull. 168, 144.—W. T.
51.90	.210	Laurdalite	Lunde, Norway	E. K., III, 375.—W. T.
51.10	.173	Covite	Nosy Komba, Madagascar	M. M., 204.
50.50	.143	Nephelite-monzonite	Rongstock, Bohemia	T. M. P. M., XIV, 98, 99.—W. T.
50.26	.210	Nephelite-syenite- porphyry.	Viezzena, Tyrol	K. A. W. W., CXI, I, 275.
49.90	.155 (49.3)	Leucite-kulaite	Kula, Asia Minor	J. G., VIII, 613.—W. T.
48.69	.151 (49.0-150)	Olivine-essexite	Mount Johnson, Quebec	J. G., XI, 265.
48.46	.243	Heumite	Lougendal, Norway	E. K., III, 376.—W. T.
48.35	.161	Kulaite	Kula, Asia Minor	J. G., VIII, 613.—W. T.
47.94	.150 (48.3)	Essexite	Salem Neck, Mass	Rosenbusch, El., 172.—W. T.
47.67	.150 (48.0)	Theralite	Alabaugh Creek, Mont	Bull. 168, 124.—W. T.
46.48	.162	Monchiquite	Rio de Janeiro, Brazil	Rosenbusch, El., 235.—W. T.

Classified list of analyses used in constructing diagrams—Continued.

RANG 3. SALEMASE.

SUBRANG 4. SALEMASE.

(II. 6, 3, 4.)

Silica con- tent.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
50.47	0.132	Augite-diorite	Silver Cliff, Colo.....	Bull. 168, 147.—W. T.
49.95	.132	Microessexite	Noey Kamba, Madagascar.....	M. M., 204.
48.50	.138	Essexite	Jangoa, Madagascar.....	Do.
46.40	.151	Augite-diorite	Ullernas, Norway	Z. K., XVI, 49.—W. T.
45.32	.110	Hornblende-gabbro ..	Salem Neck, Mass.....	J. G., VII, 68.—W. T.
43.66	.142	Essexite	Cabo Frio Island, Brazil	Rosenbusch, El., 172.—W. T.

SUBRANG 5. ———.

(II. 6, 3, 5.)

47.80	0.137	Basalt	Pedregal, Mexico	W. T.
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RANG 4. ———.

SUBRANG 3. ———.

(II. 6, 4, 3.)

45.76	0.086	Gabbro	Rossweln, Saxony.....	N. J., 1893, II, 508.—W. T.
45.11	.090	Diorite	Lindenfeld, Hesse.....	W. T.

ORDER 7. ITALARE.

RANG 1. LUJAVRASE.

SUBRANG 3. JANEIROSE.

(II. 7, 1, 3.)

51.93	0.278	Leucite-tinguaite.....	Bearpaw Mountains, Mont.....	Bull. 168, 136.—W. T.
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SUBRANG 4. LUJAVROSE.

(II. 7, 1, 4.)

54.14	0.238	Lujavrite	Tschasnatschorr, Finland.....	Rosenbusch, El., 126.—W. T.
52.25	.255	Chibinite	Umptek, Finland.....	Fennia, XI, 2, 132.—W. T.
51.94	.208 (51.6)	Camptonitic-tinguaite	Picota, Portugal.....	T. M. P. M., XVI, 272.—W. T.
50.63	.271	Nephelite-porphry ..	Laugendal, Norway	E. K., III, 157.—W. T.
48.86	.234	Allochettite	Allochet, Monzoni, Tyrol	A. W. W., 1902, Anz. XXI.

RANG 2. VULTURASE.

SUBRANG 2. ———.

(II. 7, 2, 2.)

50.32	0.157	Basanite	Vesuvius	R. T., 1861, 25.
49.73	.158 (49.6)	Leucite-tephrite	Bracciano, Italy.....	J. G., V, 370.—W. T.
47.89	.161 (47.8)	Leucitite	do	Do.

CHEMICAL COMPOSITION OF IGNEOUS ROCKS.

Classified list of analyses used in constructing diagrams—Continued.

SUBRANG 3. ———.
(II. 7, 2, 3.)

Silica con- tent.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
48.08	0.167	Basanite.....	Granatello, Vesuvius.....	R. T., 1861, 25.

SUBRANG 4. VULCANOSE.
(II. 7, 2, 4.)

42.45	0.229	Hadiynophyre.....	Melfi, Italy.....	Rosenbusch, Fl., 357.
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RANG 3. ———.
SUBRANG 3. ———.
(II. 7, 3, 3.)

47.40	0.130	Leucite-tephrite.....	Isola Monfina, Italy.....	J. G., V, 370.—W. T.
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ORDER 8. CAMPANARE.

RANG 1. ———.
SUBRANG 3. ———.
(II. 8, 1, 3.)

50.00	0.267	Tinguaite.....	Beemerville, N. J.....	Bull. Mus. Comp. Zool., XXXVIII, 1902, 276.—W. T.
45.49	.286	Leucitite.....	Ekimle Volcano, Kamerund, Africa..	W. T.

SUBRANG 5. ———.
(II. 8, 1, 5.)

47.43	0.333	Soda-sneezite.....	Penikkavaara, Finland.....	B. C. G. F., XI, 22.—W. T.
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RANG 2. VESUVASE.
SUBRANG 2. VESUVOSE.
(II. 8, 2, 2.)

47.71	0.157	Leucite-basanite.....	Lava of 1631, Vesuvius.....	W. T.
47.65	.157	do.....	Lava of 1872, Vesuvius.....	W. T.
47.53	.149	Leucitophyre.....	Vesuvius.....	R. T., 1884, LVII.
46.36	.160 (.26, 2)	do.....	do.....	R. T., 1884, LVIII.

ORDER 9. LAPPARE.

RANG 1. UETASE.
SUBRANG 3. ARKANOSSE.
(II. 9, 1, 3.)

46.40	0.252	Arkite.....	Magnet Cove, Ark.....	J. G., IX, 626.—W. T.
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Classified list of analyses used in constructing diagrams—Continued.

SUBRANG 4. URTOSE.
(II. 9, 1, 4.)

Silica con- tent.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
45.46	0.397	Urtite	Lujavr Urt, Kola, Finland	G. F. S. F., XVIII, 462.—W. T.
45.43	.391	do	do	Do.
45.28	.418	do	do	Rosenbusch, El., 126.—W. T.
43.02	.378	Ijolite, rich in nephe- lite.	Kuonosamo, Finland	B. C. G. F., XI, 17.—W. T.

CLASS III. SALFEMANE.

ORDER 3. ATLANTARE.

RANG 1. ROCKALLASE.

SUBRANG 2. ———.
(III. 3, 1, 2.)

68.75	0.144	Pantellerite	Pantellaria	Z. K., VIII, 179.—W. T.
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SUBRANG 5. ROCKALLOSE.
(III. 3, 1, 5.)

73.60	0.091	Rockallite	Rockall Island, Atlantic Ocean	Geol. Mag., VI, 163.—W. T.
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ORDER 4. VAALARE.

RANG 3. VAALASE.

SUBRANG 4. VAALOSE.
(III. 4, 3, 4.)

53.39	0.068	Quartz-gabbro	Harz	R. T., 1884, XXXIV.
53.35	.067 (52.8)	Basalt	Teanaway River, Kittitas County, Wash.	Bull. 168, 225.—W. T.
52.67	.047 (52.9)	Olivine-diabase	Cape Colony, Africa	N. J., 1887, V, 249.—W. T.
52.22	.048 (51.9-.051)	Olivine-diabase-por- phyrite.	do	Do.

RANG 4. ———.
SUBRANG 3. ———.
(III. 4, 4, 3.)

56.18	0.036	Diorite	Washington, D. C.	Bull. 168, 44.—W. T.
45.75	.027	Melaphyre	Holmestrand, Norway	Z. K., XVI, 27.—W. T.

RANG 5. ———.
(III. 4, 5.)

47.00	0.008	Olivine-gabbro-dia- base.	Sölväberget, Norway	Z. K., XVI, 27.—W. T.
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Classified list of analyses used in constructing diagrams—Continued.

ORDER 5. GALLARE.

RANG 1. ORENDASE.

SUBRANG 1. ORENDASE.

(III. 5, 1, 1.)

Silica con- tent.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
54.17	0.160	Orendite	Leucite Hills, Wyo	Bull. 168, 86.—W. T.
54.08	.163	do	do	Do.
53.70	.160 (53.6)	Wyomingite	do	Bull. 168, 85.—W. T.

SUBRANG 2. —.

(III. 5, 1, 2.)

50.23	0.150	Wyomingite	Leucite Hills, Wyo	Bull. 168, 85.—W. T.
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RANG 2. KILAUASE.

SUBRANG 2. PROWERSOSE.

(III. 5, 2, 2.)

50.41	0.113	Syenitic lamprophyre	Two Buttes, Colo	Bull. 168, 165.—W. T.
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SUBRANG 3. LAMAROSE.

(III. 5, 2, 3.)

48.98	0.107	Shonkinite	Yogo Peak, Mont	Bull. 168, 128.—W. T.
48.95	.097	Absarokite	Hoodoo Mountain, Wyo	Bull. 168, 99.—W. T.
47.56	.099	Mica-picrophyre	North of Prag, Bohemia	R. T., 1879, XLVI.
47.32	.090 (47.5)	Leucite-absarokite ...	Sunlight Valley, Wyo	Bull. 168, 97.—W. T.

SUBRANG 4. KILAUOSE.

(III. 5, 2, 4.)

46.52	0.085 (45.2)	Basalt	Volcano Butte, Castle Mountains	Bull. 168, 130.—W. T.
43.35	.099	Augitite	Mittelgebirge, Bohemia	Rosenbusch, Fl., 363.

RANG 3. CAMPTONASE.

SUBRANG 2. ABSAROKOSE.

(III. 5, 3, 2.)

49.71	0.090	Absarokite	Cache Creek, Yellowstone Park	Bull. 168, 99.—W. T.
49.03	.082	Leucite-basanite	Bolsena, Italy	J. G., V. 370.—W. T.
48.36	.080	Absarokite	Clark Fork, Wyo	Bull. 168, 99.—W. T.

Classified list of analyses used in constructing diagrams—Continued.

SUBRANG 3. KENTALLENÖSE.
(III. 5, 3, 3.)

Silica con- tent.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
52.09	0.074	Kentallenite	Glen Shira, Argyllshire, Scotland	Q. J. G. S., LVI, 537.—W. T.
51.76	.083	Absarokite	Absaroka Range, Yellowstone Park ..	Bull. 168, 99.—W. T.
51.65	.107	Lamprophyre	Cottonwood Canyon, Mont.	Bull. 168, 112.—W. T.
50.82	.075	do	Antelope and South Boulder creeks, Mont.	Bull. 168, 113.—W. T.
50.35	.101	Olivine-monzonite ..	Smällingen, Sweden	E. K., II, 46.—W. T.

SUBRANG 4. CAMPTONÖSE.
(III. 5, 3, 4.)

54.56	0.067	Quartz-basalt.....	Cinder Cone, Cal.....	Bull. 168, 185.—W. T.
53.56	.077	Mica-porphyrý	Crandall Basin, Wyo	Bull. 168, 92.—W. T.
52.35	.067	Diorite	Little Falls, Minn	N. J., 1877, 129.
51.81	.077	Gabbro-porphyrý.....	Crandall Basin, Wyo	Bull. 168, 92.—W. T.
51.23	.076	Diabase	Halleberg, Sweden.....	Rosenbusch, El., 322.
49.35	.074	Dolerite	Pantellaria.....	T. M. P. M., 1883, 393.
48.60	.095 (48.4)	Nephelite-basalt.....	Elkhead Mountains, Colo	Fortieth Par., I., 676.
48.22	.084	Camptonite.....	Mount Ascutney, Vt.....	Bull. 168, 26.—W. T.
47.91	.086	Basalt	Washoe, Nev	
47.90	.094	Essexite	Tofteholmen, Norway.....	E. K., II, 375.—W. T.
47.28	.083	Leucite-absarokite ..	Ishawooa Canyon, Wyo	Bull. 168, 99.—W. T.
47.16	.077	Gabbro	Elizabethtown, N. Y.....	Bull. 168, 37.—W. T.
46.74	.089	do	do	Do.
45.30	.107	Basalt	Mount Trumbull, Ariz	Bull. 168, 174.—W. T.
40.60	.078	Camptonite.....	Maena, Grän, Norway.....	E. K., III, 376.—W. T.

SUBRANG 5. ORNÖSE.
(III. 5, 3, 5.)

54.14	0.074	Tachylite.....	Hanover.....	R. T., 1879, LXXIV.
46.11	.081 (.077)	Örnölte.....	Örnö, Sweden	G. F. S. F., XV, 108.—W. T.

RANG 4. AUVERGNASE.

SUBRANG 2. ———.
(III. 5, 4, 2.)

50.03	0.062 (49.4)	Lamprophyre	South Boulder Creek, Mont	Bull. 168, 113.—W. T.
46.86	.065	Diabase-pitchstone ..	Meriden, Conn	Bull. 168, 35.—W. T.

SUBRANG 3. AUVERGNÖSE.
(III. 5, 4, 3.)

53.13	0.053	Diabase.....	Jersey City, N. J.....	A. J. S., IX, 1875, 187.
52.42	.046	do	Wintergreen Lake, Conn.....	A. J. S., IX, 1875, 189.
52.68	.057	Dolerite	Mount Holyoke, Mass.....	A. J. S., IX, 1875, 186.
51.78	.044	Diabase	New Haven, Conn.....	Do.
51.46	.057	Gabbro	Sturgeon Falls, Mich.....	Bull. 168, 70.—W. T.

Classified list of analyses used in constructing diagrams—Continued.

SUBRANG 3. ARVERGNOSE—Continued.

Silica con- tent.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
51.36	0.040	Basalt	Orange, N. J.	Bull. 168, 39.—W. T.
50.89	.053	do	Lassen Peak, Cal	Bull. 168, 186.—W. T.
49.87	.062	do	Pantellaria	T. M. P. M., 1883, 393.
49.63	.055 (49.5)	Diabase	Mount Ascutney, Vt.	Bull. 168, 26.—W. T.
49.18	.035	Basalt	Disko, Greenland	T. M. P. M., 1874, 120.
48.23	.034	Norite	Crystal Falls, Mich.	Bull. 168, 67.—W. T.
48.04	.045	Basalt	Ovifak, Greenland	T. M. P. M., 1874, 121.
47.93	.047 (47.7)	do	Paynes Creek, Cal	Bull. 168, 186.—W. T.
47.90	.043 (47.4-.040)	Diabase	Penokee-Gogebic Range, Mich.	Bull. 168, 73.—W. T.
47.54	.070 (47.8-.079)	Basalt	Grant, N. Mex.	Bull. 168, 170.—W. T.
47.45	.062	Gabbro	Saleix, Pyrenees	C. G. I., VIII, 1901, 832.—W. T.
47.29	.029	Pyroxene-riegite	Lherz, Pyrenees	C. G. I., VIII, 1901, 833.—W. T.
45.66	.049	Olivine-gabbro	Birch Lake, Minn.	Bull. 168, 81.—W. T.
44.90	.033	Pyroxene-riegite	Tue d'Ess, Pyrenees	C. G. I., VIII, 1901, 833.—W. T.
44.97	.072	Gabbro	Elizabethtown, N. Y.	Bull. 168, 37.—W. T.
44.77	.057	Basalt	Kosk Creek, Cal	Bull. 168, 186.—W. T.
43.50	.062	Hornblende-monchi- quite.	Magnet Cove, Ark	Rosenbusch, El., 235.—W. T.
42.77	.063	Olivine-diabase	Campton, N. H.	A. J. S. XVII, 1879, 150.
42.68	.045	Ariegite	Escourgeat, Pyrenees	C. G. I., VIII, 1901, 833.—W. T.
42.03	.053 (.055)	Fourchite	Fourche Mountain, Ark.	I. R. A., 108.—W. T.

RANG 5. KEDABEKANE.

(III. 5, 5.)

48.02	0.010	Norite	McKinseys Mill, Md.	Bull. 168, 45.—W. T.
47.09	.014	Ariegite	Lherz, Pyrenees	C. G. I., VIII, 1901, 833.—W. T.
44.76	.020	Hypersthene-gabbro	Wetheredville, Md.	Bull. 168, 44.—W. T.
44.64	.017 (45.1)	Kedabekite	Kedabek, Russia	W. T.
44.38	.019 (43.8)	Ariegite	Lherz, Pyrenees	C. G. I., VII, 1901, 833.—W. T.
44.11	.012	Kedabekite	Kedabek, Russia	W. T.
42.32	.025	Ariegite	Lherz, Pyrenees	C. G. I., VIII, 1901, 833.—W. T.
38.95	.029	do	do	Do.

ORDER 6. PORTUGARE.

RANG 1. WYOMINGANE.

SUBRANG 3. —.

(III. 6, 1, 3.)

50.00	0.110	Shonkinite	Bearpaw Mountains, Mont.	Bull. 168, 136.—W. T.
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SUBRANG 4. —.

(III. 6, 1, 4.)

48.39	0.121 (48.5)	Analcite-basalt	Little Belt Mountains, Mont.	Bull. 168, 128.—W. T.
45.72	.166	Monchiquite	Fohnberges, Baden	W. T.
42.30	.157	Nephelinite	Katzenbuekel, Odenwald	Rosenbusch, El., 357.
40.03	.140 (40.2)	Camptonite	Oxford, N. J.	Rosenbusch, El., 235.—W. T.

Classified list of analyses used in constructing diagrams—Continued.

RANG 2. MONCHIQUESE.

SUBRANG 3. SHONKINORE.

(III. 6, 2, 3.)

Silica con- tent.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
49.59	0.139	Leucite-syenite.....	Highwood Mountains, Mont	Bull. 168, 132.—W. T.
48.05	.142 (48.5)	Shonkinite	Maros, Celebes	G. C., 23.
47.98	.136	Leucite-basalt	Highwood Mountains, Mont	Bull. 168, 132.—W. T.
46.73	.088 (45.9)	Shonkinite	Square Butte, Mont	B. G. S. A., VI, 414.—W. T
45.19	.101 (44.8)	Nephelite-basalt	Breitfirst, Hesse	Rosenbusch, El., 357.
43.85	.150	Leucite-monchiquite	Mittelgebirge, Bohemia	Rosenbusch, El., 235.—W. T.

SUBRANG 4. MONCHIQUESE.

(III. 6, 2, 4.)

48.43	0.114	Hornblende-vogesite	Hohwald, Elsass	Rosenbusch, El., 231.
47.82	.121	Monchiquite	Highwood Mountains, Mont	Bull. 168, 132.—W. T.
45.59	.110 (45.8)	Analcite-basalt	Pikes Peak district, Colo	Bull. 168, 146.—W. T.
45.56	.154	Nephelite-tephrite	Herrnberg, Tetschen, Bohemia	W. T.
44.54	.124	Limburgite	Heldburger Feste, S. Thüringen	Rosenbusch, El., 363.
43.84	.119	Leucite-basanite	Blankenhornberg, Kaiserstuhl, Baden	W. T.

RANG 3. LIMBURGASE.

SUBRANG 3. OUROSE.

(III. 6, 3, 3.)

46.65	0.114	Labradorite-porphyr	Wildkaar, Tyrol	R. T., 1879, XLIV.
43.74	.108	Monchiquite	Rio do Ouro, Brazil	Rosenbusch, El., 235.—W. T.
42.46	.068	do	Willow Creek, Mont	Bull. 168, 130.—W. T.

SUBRANG 4. LIMBURGOSE.

(III. 6, 3, 4.)

46.60	0.112 (46.3)	Nephelite-gabbro	Nosy Komba, Madagascar	M. M., 204.
46.35	.086	Nephelite-basanite	Römhild, S. Thüringen	Rosenbusch, El., 346.
44.82	.073 (44.5—, 074)	Paleolimburgite	Atacama, Chile	Z. D. g. G., LI, 4.
43.65	.071 (43.8)	Olivine-gabbro-dia- base	Brandberget, Gran, Norway	Q. J. G. S., L, 19.—W. T.
43.50	.107	Augitite	Limberg, Baden	W. T.
41.01	.082	Hornblende-basalt	Sparbrod, Rhone	N. J., 1882, II, 155.
40.70	.064 (40.5)	Limburgite	Oberersteinberg, Lausitzer Moun- tains, Prussia	Rosenbusch, El. 363.
40.10	.109 (40.4)	Ijolite	Ampasibitika, Madagascar	M. M., 204.
37.90	.095	Hornblendite	Brandberget, Gran, Norway	Q. J. G. S., L, 19.—W. T.

SUBRANG 5. ———.

(III. 6, 3, 5.)

41.94	0.121	Camptonite	Campton Falls, N. H	A. J. S., XVII, 1879, 150.
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Continued Construction of New York State

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Adhikari. K. Subbarama Murthy.

مجلسه ۱۰۰۰

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Classified list of analyses used in constructing diagrams—Continued.

RANG 3. ETINDASE.

SUBRANG 4. ETINDOSE.

(III, 7, 3, 4.)

Silica con- tent.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
40.52	0.097	Nephelite-basalt.....	Hesse-Darmstadt.....	Rosenbusch, El., 357.
39.33	.109	do.....	Mittelgebirge, Bohemia.....	Do.
38.46	.143 (38.9)	Camptonite.....	Mulatto, Predazzo, Tyrol.....	K. A. W. W., CXI, I, 234.

ORDER 8. BOHEMARE.

RANG 1. CHOTASE.

SUBRANG 2. CHOTOSE.

(III, 8, 1, 2.)

46.51	0.167	Leucitite.....	Bearpaw Mountains, Mont.....	Bull. 168, 136.—W. T.
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RANG 2. ALBANASE.

SUBRANG 2. ALBANOSE.

(III, 8, 2, 2.)

47.47	0.137	Leucite-tephrite.....	Vesuvius, lava of 1760.....	R. T., 1894, LVI.
45.99	.168 (46.1)	Leucitite.....	Capo di Bove, Italy.....	A. J. S., IX, 1900, 53.—W. T.

SUBRANG 3. ———.

(III, 8, 2, 3.)

41.24	0.141	Nephelinite.....	Laacher See, Rhine province.....	Rosenbusch, El., 357.
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SUBRANG 4. COVOSE.

(III, 8, 2, 4.)

43.18	0.186	Theralite.....	Crazy Mountains, Mont.....	Rosenbusch, El., 176.
42.06	.132	Limburgite.....	Habichtswald, Hesse.....	Rosenbusch, El., 363.
41.74	.204	Ijolite.....	Magnet Cove, Ark.....	J. G., IX, 618—W. T.
40.15	.204 (40.3)	Nephelinite.....	Etinde Volcano, Kamerun, Africa...	W. T.
38.39	.150	do.....	do.....	Do.

ORDER 9. FINNARE.

RANG 1. IJOLASE.

SUBRANG 2. MADUPOSE.

(III, 9, 1, 2.)

42.65	0.139	Madupite.....	Leucite Hills, Wyo.....	Bull. 168, 85.—W. T.
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Classified list of analyses used in constructing diagrams—Continued.

SUBRANG 4. IIVAAROSE.
(III. 9, 1, 4.)

Silica con- tent.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
45.64	0.342	Nephelite-porphry ..	Umptek, Finland	Fennia, XI, 2, 196.—W. T.
43.70	.257	Ijolite	Kuusamo, Finland	B. C. G. F., XI, 16.—W. T.
42.18	.268	Nephelite-basalt.....	Bauersberg, Bavaria	R. T., 1879, LXII.

SUBRANG 5. IJOLOSE.
(III. 9, 1, 5.)

42.07	0.281	Ijolite	Kuusamo, Finland	B. C. G. F., XI, 16.—W. T.
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CLASS IV. DOFFEMANE.

ORDER 1. HUNGARARE.

SECTION 1. MINNESOTIARE.

RANG 1. MINNESOTASE.

SECTION 1. MINNESOTIASE.

SUBRANG 2. COOKOSE.
(IV. 1, 1, 1, 1, 2.)

51.83	0.005	Pyroxenite	Meadow Creek, Mont	Bull. 168, 114.—W. T.
50.64	.020	Wehrlite	New Braintree, Mass	Bull. 168, 33.—W. T.
46.96	.030	Hypersthene-gabbro ..	Gunflint Lake, Minn.....	Bull. 168, 81.—W. T.

SECTION 2. ———.

RANG 1. ———.

SECTION 2. ———.

SUBRANG 1. BELCHEROSE.
(IV. 1, 2, 1, 2, 1.)

48.63	0.008	Peridotite	Belchertown, Mass.....	Bull. 168, 30.—W. T.
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SUBRANG 2. ———.
(IV. 1, 2, 1, 2, 2.)

48.91	0.013	Olivine-gabbro	Orange Grove, Md.....	Bull. 168, 41.—W. T.
46.56	.050	Gabbro	Pharkowsky-Ouwal, Ural Mountains.	O. N., 145.
46.56	.043 (46.9)	do	Near Koswinsky, Ural Mountains....	Do.
46.06	.098	Missourite	Shonkin Creek, Mont	Bull. 168, 133.—W. T.
44.94	.000	Wehrlite	Koswinsky, Ural Mountains.....	O. N., 173.
44.39	.032	Gabbro	Pharkowsky-Ouwal, Ural Mountains.	O. N., 145.

Classified list of analyses used in constructing diagrams—Continued.

SECTION 3. HUNGARIARE.

RANG 1. WEHRLASE.

SECTION 1. WEHRLIASE.

SUBRANG 2. WEHRLOSE.

(IV. 1, 3, 1, 1, 2.)

Silica con- tent.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
48.95	0.040	Wehrlite	Red Bluff, Mont.....	Bull. 168, 114.—W. T.
46.13	.001	Hornblende-pierite ..	Meadow Creek, Mont.....	Do.
45.68	.000	Lherzolite	Baldasser, Piedmont, Italy	Rosenbusch, El., 165.

SECTION 2. ———.

SUBRANG 2. ROESWEINORE.

(IV. 1, 3, 1, 2, 2.)

47.75	0.027	Peridotite	Cathay Hill, Mariposa County, Cal...	Bull. 168, 209.—W. T.
46.00	.035 (46.1)	Hornblendite	Col d'Eret, Pyrenees	C. G. I., VIII, 1901, 833.—W. T.
44.99	.028	Wehrlite	Crystal Falls, Mich.....	Bull. 168, 67.—W. T.

SECTION 4. ———.

RANG 1. CORTLANDTASE.

SECTION 1. CORTLANDTIASE.

SUBRANG 1. CORTLANDTOSE.

(IV. 1, 4, 1, 1, 1.)

44.64	0.000	Lherzolite	Lherz, Pyrenees.....	C. G. I., VIII, 1901, 833.—W. T.
36.80	.049	Peridotite	Syracuse, N Y	Bull. 168, 38.—W. T.

SUBRANG 2. CUSTERORE.

(IV. 1, 4, 1, 1, 2.)

46.03	0.041	Peridotite	Silver Cliff, Colo.....	Bull. 168, 147.—W. T.
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SECTION 5. PYRENIARE.

RANG 1. LHERZASE.

SECTION 1. LHERZIASE.

SUBRANG 1. LHERZOSE.

(IV. 1, 5, 1, 1, 1.)

41.50	0.036	Hornblende-lherzolite	Causson, Pyrenees.....	C. G. I., 1901, VIII, 833.—W. T.
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SUBRANG 2. ARGEINORE.

(IV. 1, 5, 1, 1, 2.)

39.25	0.038	Hornblende-perido- tite.	Argein, Pyrenees.....	C. G. I., 1901, VIII, 833.—W. T.
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Classified list of analyses used in constructing diagrams—Continued.

SECTION 3. VENANZIASE.

SUBRANG 2. VENANZOSE.

(IV. 1, 5, 1, 3, 2.)

Silica con- tent.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
41.43	0.152	Venanzite	San Venanzo, Umbria, Italy	A. W. B., 1899, VII, 113.—W. T.

ORDER 2. SCOTARE.

SECTION 1. ———.

RANG 1. ———.

SECTION 1. ———.

SUBRANG 2. ———.

(IV. 2, 1, 1, 1, 2.)

53.05	0.018	Augite-norite.....	Madras, India	W. T.
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SECTION 3. BRANDBERGIASE.

SUBRANG 2. BRANDBERGOSSE.

(IV. 2, 1, 1, 3, 2.)

45.05	0.030 (45.9)	Pyroxenite	Brandberg, Norway	Q. J. G. S., L, 31.—W. T.
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SUBRANG 3. ———.

(IV. 2, 1, 1, 3, 3.)

45.04	0.209	Nephelite-basalt.....	Katzenbuckel, Odenwald, Baden	Rosenbusch, El., 357.
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SECTION 2. PAOLIARE.

RANG 1. PAOLASE.

SECTION 2. ———.

SUBRANG 2. ———.

(IV. 2, 2, 1, 2, 2.)

47.41	0.031	Augite-peridotite.....	Peckskill, N. Y.	A. J. S., XXXI, 1886, 40.—W. T.
42.68	.077	Hornblende-basalt ...	Hauk, S. Rhone	Rosenbusch, El., 309.
40.42	.038	Olivine-gabbro.....	Crazy Mountains, Mont	Bull. 168, 122.—W. T.
40.15	.000	Koswite	Koswinsky, Ural Mountains	O. N., 119.
39.59	.057	Nephelite-basalt	Ottendorf, Silesia.....	R. T., 1884, LXIV.

SECTION 3. PAOLIASE.

SUBRANG 2. PAOLOSE.

(IV. 2, 2, 1, 3, 2.)

41.44	0.000 (41.6)	Koswite	Koswinsky, Ural Mountains.....	O. N., 119.
38.39	.031 (37.5)	Jacupirangite	Magnet Cove, Ark.....	J. G., IX, 620.—W. T.
38.38	.022	do	Sao Paulo, Brazil.....	Do.
36.51	.075	Eleolite-mica-syenite.	Magnet Cove, Ark.....	Do.

SECTION 3. TEXTIARE.

RANG 1. TEXASE.

SECTION 1. MARQUETTIASE.

SUBRANG 2. MARQUETTOSE.

(IV. 2, 3, 1, 1, 2.)

Silica content.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
39.37	0.017	Peridotite	Opin Lake, Mich.	Bull. 168, 64.—W. T.

SECTION 2. UVALDIASE.

SUBRANG 2. UVALDOSE.

(IV. 2, 3, 1, 2, 2.)

40.32	0.080	Nephelite-basalt	Uvalde County, Tex.	Bull. 168, 62.—W. T.
39.92	.063 (41.0)	do	do	Bull. 168, 63.—W. T.
39.16	.081	do	Oberleinleiter, Baden	Rosenbusch, El., 357.
36.53	.108	Nephelite-melilite-basalt.	Wartenberg, Baden	Rosenbusch, El., 360.

SECTION 4. ———.

RANG 1. CASSELADE.

SECTION 2. CASSELIASE.

SUBRANG 1. ———.

(IV. 2, 4, 1, 2, 1.)

38.34	0.106	Limburgite	Rio de Janeiro, Brazil	T. M. P. M., XX, 304.
37.98	.121 (37.4)	Melilite-nephelite-basalt.	Hohenberg, Westphalia	Rosenbusch, El., 357.

SUBRANG 2. CASSELOSE.

(IV. 2, 4, 1, 2, 2.)

39.20	0.056 (38.6)	Dike-rock	Kola Peninsula, Finland	Fennia, 15, 2, 1899, 27.—W. T.
37.96	.066	Nephelite-melilite-basalt.	Uvalde County, Tex	Bull. 168, 63.—W. T.

SECTION 5. ———.

RANG 1. ———.

SECTION 1. KALTENIASE.

SUBRANG 3. KALTENOSE.

(IV. 2, 5, 1, 1, 3.)

34.98	0.101	Mica-peridotite	Kaltenthal, Harzburg, Harz Mts	Rosenbusch, El., 165.—W. T.
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Classified list of analyses used in constructing diagrams—Continued.

ORDER 3. SVERIGARE.

SECTION 1. BERGENIARE.

RANG 1. BERGENARE.

SECTION 1. BERGENIASE.

SUBRANG 3. BERGENOSE.

(IV. 3, 1, 1, 1, 3.)

Silica con- tent.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
31.59	0.032	Ilmenite-norite.....	Storgangen, Norway	B. M. A., 1896, V, 165.—W. T.

SECTION 2. ———.

RANG 1. ———.

SECTION 2. ———.

SUBRANG 2. ———.

(IV. 3, 2, 1, 2, 2.)

38.20	0.122	Nephelite-melilitite- basalt.	Burgstall, Baden	Rosenbusch, El., 360.—W. T.
38.18	.036	(?) Pyroxenite.....	Predazzo, Tyrol	E. K., II, 76.—W. T.

SECTION 3. AVEZACIASE.

SUBRANG 3. AVEZACOSE.

(IV. 3, 2, 1, 3, 3.)

31.80	0.026	Avezacite	Avezac-Prat, Pyrenees	C. G. L., VIII, 1901, 832.—W. T.
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ORDER 4. ADIRONDACKARE.

Suborder 2. Adirondackore.

RANG 1. ADIRONDACKARE.

SECTION 1. ADIRONDACKIASE.

SUBRANG 3. ———.

(IV. 4, 2, 1, 1, 3.)

24.74	0.000	Iron ore	Ulfö, Sweden.....	S. M. Q., XXI, 60.
22.87	.000	Iron ore	Cumberland Hill, R. I	S. M. Q., XXI, 60.
14.95	.000	do	Laanghult, Sweden	Do.

SUBRANG 4. ———.

(IV. 4, 2, 1, 1, 4.)

21.42	0.033	Iron ore	Elizabethtown, N. Y	S. M. Q., XX, 343.
11.73	.055	do	do	Do.
10.37	.057	do	Frontenac County, Ontario	S. M. Q., XX, 331.

Suborder 3. Champlainore.

RANG 1. CHAMPLAINASE.

SECTION 1. CHAMPLAINIASE.

SUBRANG 4. ———.

(IV. 4, 3, 1, 1, 4.)

Silica con- tent.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
17.90	0.000	Iron ore	Split Rock mine, N. Y.....	S. M. Q., XX, 343.
13.35	.000	do	Tunnel Hill, N. Y.....	Do.

ORDER 5. ———.

Suborder 2. ———.

RANG 1. ———.

SECTION 1. ———.

SUBRANG 4. ———.

(IV. 5, 2, 1, 1, 4.)

10.77	0.039	Iron ore	Pine Lake, Ontario.....	S. M. Q., XX, 331.
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SUBRANG 5. ———.

(IV. 5, 2, 1, 1, 5.)

10.26	0.000	Iron ore	Iron Mountain, N. Y.....	S. M. Q., XX, 343.
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SECTION 2. ———.

SUBRANG 4. ———.

(IV. 5, 2, 1, 2, 4.)

9.79	0.000 (9.5)	Iron ore	Millford Pit, N. Y.....	S. M. Q., XX, 344.
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CLASS V. PERFEMANE.

ORDER 1. MAORARE.

SECTION 1. CAROLINIARE.

RANG 1. WEBSTERASE.

SECTION 1. MARICIASE.

SUBRANG 1. MARICOSE.

(V. 1, 1, 1, 1, 1.)

55.52	0.000	Lherzolite	Locano, Piedmont.....	Rosenbusch, El., 165.
55.23	.000	Pyroxenite	Marico district, Transvaal.....	A. J. S., VII, 1899, 318.—W. T.

CHEMICAL COMPOSITION OF IGNEOUS ROCKS.

Classified list of analyses used in constructing diagrams—Continued.

SECTION 2. WEBSTERIASE.

SUBRANG 1. WEBSTEROSE.

(V. 1, 1, 1, 2, 1.)

Silica con- tent.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
53.14	0.005	Websterite.....	Webster, N. C.....	Bull. 168, 53.—W. T.
53.98	.000	do.....	Hebbville, Md.....	Bull. 168, 43.—W. T.
52.55	.004	do.....	do.....	Bull. 168, 43.—W. T.

SUBRANG 2. CECILOSE.

(V. 1, 1, 1, 2, 2.)

53.21	0.008	Websterite.....	Cecil County, Md.....	Bull. 168, 43.—W. T.
53.25	.008 (53.6)	Pyroxenite.....	Mount Diablo, Cal.....	Bull. 168, 213.—W. T.

SECTION 2. MARYLANDIARE.

RANG 1. BALTIMORASE.

SECTION 2. BALTIMORIASE.

SUBRANG 2. BALTIMOROSE.

(V. 1, 2, 1, 2, 2.)

50.80	0.000 (50.6)	Pyroxenite.....	Johnny Cake road, Md.....	Bull. 168, 42.—W. T.
49.35	.000	Kowwite.....	Kowwinsky, Ural Mountains.....	O. N., 119.

SECTION 3. ———.

RANG 1. ———.

SECTION 2. ———.

SUBRANG 2. KOWWORE.

(V. 1, 3, 1, 2, 2.)

43.20	0.00	Kowwite.....	Kowwinsky, Ural Mountains.....	O. N., 119.
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SECTION 4. ———.

RANG 1. ———.

SECTION 1. ———.

SUBRANG 1. ———.

(V. 1, 4, 1, 1, 1.)

41.43	0.00	Saxonite.....	Riddies, Oreg.....	Bull. 168, 221.—W. T.
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SUBRANG 2. ———.

(V. 1, 4, 1, 1, 2.)

42.39	0.000	Peridotite.....	Goose Bay, Straits of Magellan.....	W. T.
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SECTION 5. MAORIARE.

RANG 1. DUNASE.

SECTION 1. DUNIASE.

SUBRANG 1. DUNOSE.

(V. 1, 5, 1, 1, 1.)

Silica con- tent.	Alkali-silica ratio.	Author's name.	Locality.	Reference..
42.80	0.000	Dunite	Dun Mountains, New Zealand	Rosenbusch, El., 165.
40.11	.000	Dunite	Corundum Hills, N. C.	Bull. 168, 54.—W. T.
39.99	.00 (39.7)	Harzburgite	Olivine Hills Range, New Zealand....	Rosenbusch, El., 165.

ORDER 2. ———.

SECTION 2. ———.

RANG 1. ———.

SECTION 2. ———.

SUBRANG 2. ———.

(V. 2, 2, 1, 2, 2.)

43.87	0.000	Lherzolite	Johnny Cake road, Md.	Bull. 168, 42.
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SECTION 5. ———.

RANG 1. ———.

SECTION 1. ———.

SUBRANG 2. PERMOSE.

(V. 2, 5, 1, 1, 2.)

31.84	0.000	Dunite sidéronitique.	Koswinsky, Ural Mountains	O. N., 128.
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ORDER 3. ———.

SECTION 4. ———.

RANG 1. ———.

SECTION 1. ———.

SUBRANG 2. ———.

(V. 3, 4, 1, 1, 2.)

21.25	0.000	Iron ore	Taberg, Sweden	S. M. Q., XXI, 60.
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CHEMICAL COMPOSITION OF IGNEOUS ROCKS.

Classified list of analyses used in constructing diagrams—Continued.

ORDER 4. ———.

Suborder 2. ———.

RANG 1. ———.

SECTION 1. ———.

SUBRANG 2. ———.

(V. 4, 2, 1, 1, 2.)

Silica conc. total	Alkali-silica ratio.	Author's name.	Locality.	Reference.
20.85	0.000	Iron ore	Cumberland Hill, R. 1	S. M. Q., XX, 351.
SUBRANG 4. ———.				
(V. 4, 2, 1, 1, 4.)				
16.17	0.000	Iron ore	Iglanala, Sweden	S. M. Q., XXI, 60.
7.82	0.000	do	Horton, Renfrew County, Canada ...	S. M. Q., XX, 331.

ORDER 5. ———.

Suborder 2. ———.

RANG 1. ———.

SECTION 1. ———.

SUBRANG 2. ———.

(V. 5, 2, 1, 1, 2.)

4.08	0.002	Magnetite-splendite ..	Routivara, Sweden	Z. P. G.
SUBRANG 3. ———.				
(V. 5, 2, 1, 1, 3.)				
7.32	0.000	Iron ore	Leeds County, Ontario	S. M. Q., XX, 331.
6.88	0.000	do	Alms, Sweden	S. M. Q., XXI, 60.
SUBRANG 5. ———.				
(V. 5, 2, 1, 1, 5.)				
8.82	0.000	Iron ore	Mill Pond pit, N. Y.	S. M. Q., XX, 344.
8.02	0.000	do	Mayhew Iron Range, Minn.	S. M. Q., XX, 337.
1.47	0.000	do	Eagle Lake mine, Phenixville County Ontario	S. M. Q., XX, 332.
8.2	0.000	do	Saukford, N. Y.	S. M. Q., XX, 346.

SUBORDER 3. ———.

RANG 1. ———.

SECTION 1. ———.

SUBRANG 4. ———.

(V. 5, 3, 1, 2, 4.)

4.76	0.000	Iron ore	Iron Mountain, N.Y.	S. M. Q., XX, 336.
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DISCUSSION OF THE DIAGRAMS.

GENERAL DIAGRAMS.

On Pl. I are exhibited the comparative values of the chief chemical components of over 950 rocks. The relative molecular proportions of six oxides— Al_2O_3 , K_2O , Na_2O , CaO , MgO , and FeO ($=\text{FeO}+2\text{Fe}_2\text{O}_3$)—are expressed by the shapes of the individual diagrams, the silica percentages are expressed by the relative lateral positions of these diagrams, and the comparative richness in alkalies is shown by the shapes of the individual diagrams and is also expressed by their relative vertical positions.

In the upper left-hand corner of the plate a smaller multiple diagram shows the distribution of the analyses in a more concise manner, the several colors of the spots indicating the classes into which they may be subdivided, according to the quantitative system, to be noticed more fully on page 68.

VARIATIONS IN COMPOSITION.

From the large diagram it is seen how manifold and intricate are the variations in chemical composition of igneous rocks. The larger the yellow triangles, the richer the soda and alumina; the larger the green ones, the more the potash and alumina; the taller the upper half of the individual diagram, the more the alumina; the narrower and taller the yellow and green triangles, the greater the excess of alumina over alkalies; the larger the blue triangles, the more the magnesia and lime; the larger the red triangles, the more the iron oxide and lime; the longer these lower triangles in the direction of the middle vertical line, the more the lime. Long, narrow, inclined, blue triangles indicate an excess of magnesia over lime; long, narrow, inclined, red triangles, an excess of iron oxide over lime.

The variation in the sizes of the individual diagrams, from the small ones at the left to the large ones at the right, corresponds to the great difference in silica content of the different rocks, as well as to differences in the components just named. Rocks with 75 per cent of silica have only 25 per cent of other constituents, while rocks with 40 per cent of silica have 60 per cent of other components. Moreover, the relative number of molecules for given percentages of mass increases with the decrease in molecular weight of the component oxides. It is to be observed that rocks high in silica are relatively high in alumina and the alkalies. The molecular weights of these are: Al_2O_3 , 102; K_2O , 94; Na_2O , 62. Rocks low in silica may be high in alumina and alkalies, or high in lime, iron oxide, and magnesia. The molecular weights of the latter are: FeO , 72; CaO , 56; MgO , 40. The lightness of magnesia accounts for its greater proportions in the diagrams than in the analyses.

There are chemical variations which are somewhat regular, and others which seem irregular. First, it appears that the most siliceous rocks are rich in alumina and alkalies, and that lime increases at first more than iron and magnesia. But to this latter statement there are many exceptions.

In rocks with intermediate silica, 50 to 60 per cent, there is a gradation from those rich in alumina and alkalies and low in lime, iron, and magnesia to those rich in the latter and poor in the former. But there are rocks in this series high in alumina and lime and poor in alkalies and iron and magnesia.

The rocks low in silica, containing 35 to 50 per cent, have a wide range in variation, and attain the highest amount of magnesia. Those extremely low in silica, containing less than 30 per cent, are very rich in iron, with little or no alumina and alkalies, and little lime or magnesia.

The diagrams of rocks with less than 28 per cent of silica are found on Pl. VII. They are not repeated on Pl. I, because of the inconvenience of a plate of such length.

If the variations are studied in greater detail it is seen that in rocks having nearly the same silica and alkali ratios there is variation in the alumina, scarcely two rocks having the same amount. But there is more variation in the potash and soda. These values seem to be constantly shifting from place to place, with nothing suggesting a constant ratio between them. The great preponderance of soda is expressed by the predominance of yellow triangles over green ones. Dominantly potassic rocks are rare. They are more abundant among the more siliceous ones. Soda reaches its maximum in less siliceous rocks. Similar variability shows itself in the proportions of lime, iron oxide, and magnesia, whether these are subordinate or preponderant constituents.

TRANSITIONS AND EXTREMES.

It is possible to select certain shaped diagrams as types and discover many that are approximately the same. But closer inspection shows gradual variations from any two of these types to intermediate forms. And the general impression obtained from the whole assemblage is a regular variation from highly aluminous alkalic, yellow, and green figures to highly ferromagnesian calcic, red, and blue ones, combined with a very irregular variation in detail among adjacent figures.

The extremes of chemical variation reached in igneous rocks are exhibited in some of the diagrams. However, all known extremes are not expressed, because chemical analyses are wanting in several instances. Thus the extreme of pure silica attained by some intrusive dikes or veins of quartz is not represented. Chemical analyses have not yet been made of such rocks, or of the highly quartzose pegmatites with more than 85 per cent of silica. When they have been made the

individual diagrams will extend to the extreme left-hand point of the multiple diagram.

Individual diagrams, composed of only a green triangle, exhibit the composition of a rock almost wholly orthoclase and quartz. One that is simply a yellow triangle is an almost pure albite rock. An almost pure nephelite rock from Ontario has been described by Adams, but analyses of it have not yet been made.

Diagrams consisting of only a narrow line represent an almost pure magnesium silicate, olivine, while those consisting of long triangles sloping to the left (Pl. VII) represent iron and titanium oxide—titaniferous magnetite.

The extremes of variability expressed in mineral terms are known to be as follows: Igneous rocks wholly quartz, almost wholly feldspar, orthoclase, albite, labradorite, and other varieties of feldspar, and those wholly nephelite; rocks almost wholly enstatite, hypersthene, olivine, magnetite. From what is known of the variable mineral composition of igneous rocks it is clear that with more analyses to introduce into the diagrams the variations in the shapes of the figures would be increased. Enough are shown to demonstrate the gradual character of the variations in chemical composition, and the transitions from rocks of one composition to those of another.

RELATIVE ABUNDANCE OF DIFFERENT KINDS OF ROCKS.

The distribution of the individual diagrams in the multiple one, and of the spots in the small composite diagram of Pl. I, shows that those varieties of rocks having extreme compositions, occurring in the margin of the multiple diagram, are less abundant than those having more nearly an average composition. This is still more evident when all those analyses are taken into account which were omitted because of lack of space for them. They will be found to belong to the central portion of the multiple diagram.

This is shown on Pl. VIII in a composite diagram exhibiting the variation in silica and alkali-silica ratio of 2,000 igneous rocks, which has been prepared by combining data found in this paper with those contained in the collection of analyses published by Washington,^a to whom the author is indebted for an opportunity to study the collection in proof sheets. There are more than twice as many rocks involved in this diagram as in that on Pl. I, but the results are similar, and if the spots were replaced by individual diagrams the effect would be to doubly confirm all the conclusions drawn from a study of Pl. I. The construction of such a multiple diagram, however, is not feasible at this time.

The average rock, as calculated by Clarke^b from 680 analyses of American rocks, is shown by diagram at 59.77-0.088, and that calculated by Harker^c

^a Op. cit.

^b Bull. U. S. Geol. Survey, No. 148, p. 12.

^c Geol. Mag., 1899, p. 220.

from 397 British rocks is shown by diagram at 58.7-0.083. These diagrams resemble those of rocks having like silica and alkali-silica ratios, and occur in the densest part of the assemblage. Other averages made from greater numbers of analyses yield almost identical results. A later average, made by Clarke^a from 830 complete analyses of American rocks combined with 180 additional determinations of silica, 90 of lime, and 130 of alkalis, produce an average magma with 59.71 per cent of silica, and other constituents very nearly the same as those expressed in the diagram. Washington^b obtained a closely similar average magma from 1,811 analyses of igneous rocks from all parts of the world, having 58.24 per cent of silica. The loci of the averages of American and of British rocks are marked by crosses on the diagram on Pl. VIII.

These prove that the average of a large number of known rocks is like the commonest rocks; conversely, that the commonest rocks are like the average of all known rocks; from which it is possible to derive all kinds of igneous rocks by processes of separation, splitting up (*spaltung*), differentiation. It does not follow from this that they have been produced from one common average magma, or even that they have been produced in this manner in actual fact; but such an origin is shown to be quantitatively possible and reasonable.

ABSENCE OF CLUSTERING.

A study of the diagrams of Pl. I and Pl. VIII fails to detect any clustering or grouping of analyses in definite parts of the multiple diagram, such as might serve as the basis for a chemical classification of rocks. This is the same as stating that there do not appear any "natural" recognizable subdivisions of rocks on a basis of their chemical composition. Variations in seven prominent chemical factors exist throughout the system of igneous rocks, the mathematical expression of which would be extremely intricate. The study of the chemical composition of igneous rocks by graphical methods does not reveal any simple method of grouping or classifying them on a basis of their chemical constituents alone.

SIMILARITY OF ROCKS FROM DIFFERENT PETROGRAPHICAL PROVINCES.

Further study of the diagrams and of the list of analyses shows the chemical similarity of many rocks that belong to different petrographical provinces. One illustration of this is taken from the best-known province, that of Christiania, made classic by the publications of Brögger. The diverse rocks of this region that are genetically related may be found in various places in the list and in the multiple diagrams. A comparison of the individual diagrams with those of

^a Clarke, F. W., Bull. U. S. Geol. Survey No. 168, 1900, p. 14.

^b Washington, H. S., Chemical analyses of igneous rocks from 1884 to 1900: Prof. Paper U. S. Geol. Survey No. 14, 1908, p. 107.

similar shape from other petrographical provinces will demonstrate the truth of Brögger's statement that "the same group of differentiated rocks can be produced by separation from mother magmas of quite different chemical composition."^a A list of the chief cases of similarity is given briefly, as follows:

Table showing similarity between Norway rocks and those of other regions.

Place in classified list.	Norway rock.	Similar rocks of other regions.
I. 3, 1, 3.....	77.20-0.080	77.05-0.080, Butte, Mont. 77.03- .080, Pikes Peak district, Colo.
	76.73- .077	77.33- .079, Alaska, and others.
I. 4, 1, 3.....	76.05- .092	76.20- .091, New Mexico. 75.71- .094, Yellowstone Park, and others.
	71.49- .109	71.67- .101, Castle Mountain district, Mont. 72.06- .107, Stony Creek, Conn. 70.23- .113, Essex County, Mass.
I. 4, 2, 3.....	75.74- .086	76.00- .087, California. 75.01- .086, Alaska. 74.95- .088, Nevada.
	70.54- .107	71.88- .095, Iron Mountain, Mo. 70.92- .096, Yellowstone Park. 68.36- .105, Essex County, Mass.
I. 5, 1, 3.....	66.13- .130	66.03- .132, Custer County, Colo.
	64.04- .160	65.43- .140, Mount Ascutney, Vt.
I. 5, 1, 4.....	64.92- .146	65.51- .143, New Mexico.
	64.54- .157	63.71- .159, Essex County, Mass. 63.09- .164, Essex County, Mass. 62.17- .156, Crazy Mountains, Mont. 61.05- .147, Ischia, Italy.
I. 5, 2, 4.....	59.38- .125	63.49- .138, Custer County, Colo. 61.43- .133, Pantellaria. 58.94- .109, Silver Cliff, Colo. 58.28- .112, Crazy Mountains, Mont. 57.48- .118, Pikes Peak district, Colo.
I. 6, 1, 4.....	58.61- .194	59.20- .189, Madagascar. 58.70- .190, Crazy Mountains, Mont. 58.64- .195, Cripple Creek, Colo. 58.62- .191, Madagascar. 58.20- .190, Madagascar.
II. 5, 2, 3.....	58.00- .142	59.78- .140, Custer County, Colo.
II. 5, 2, 4.....	59.56- .125	58.42- .099, Luzon, Philippine Islands.
	56.79- .118	57.97- .116, Mount Ascutney, Vt. 57.01- .124, Silver Cliff, Colo.

^a Brögger, W. C., Quart. Jour. Geol. Soc. London, vol. 50, 1894, p. 36.

Table showing similarity between Norway rocks and those of other regions—Continued.

Place in classified list.	Norway rock.	Similar rocks of other regions.
II. 5, 3, 4	52.91-0.119	52.97-0.107, Pikes Peak district, Colo. 53.10- .134, Madagascar.
	48.06- .084	49.24- .092, Ferdinandea. 48.90- .090, Vosges. 50.56- .079, Plumas County, Cal.
III. 5, 3, 4	47.90- .094	48.22- .064, Mount Ascutney, Vt. 47.16- .077, New York.
III. 6, 3, 4	43.65- .071	42.03- .053, Arkansas.
IV. 2, 1, 1, 3, 2	45.05- .030	46.56- .043, Ural Mountains. 46.56- .050, Ural Mountains.

From this list it appears that among the various rocks, ranging from persalic to dofemic, that occur in the Christiania region there are those whose chemical composition is very similar to particular rocks found in the Ural Mountains, Vosges Mountains, Ischia, Pantellaria, Ferdinandea, Madagascar, Luzon, Vermont, New York, Massachusetts, Connecticut, Missouri, Arkansas, Colorado, New Mexico, Nevada, Yellowstone National Park, Montana, California, and Alaska. These regions belong to diverse petrographical provinces, some of them very similar to that of Christiania, but others distinctly different.

There are provinces in Finland, in Canada, and in parts of the United States closely resembling the Christiania province in the characters of their nephelite-bearing rocks, but the regions are not identical in petrography. It is possible to find all degrees of similarity between petrographical provinces in various parts of the world, and the most intricate web of similar differentiation products may be woven by their comparison.

From the chemical character of igneous magmas, their content of like elements, the chemical character of the rock-making minerals, the fixed composition of some of them, and the serial variation in the composition of others, the theory of differentiation leads us to expect diversity in the rocks of all petrographical provinces of such a kind that identical or closely similar varieties of rocks will occur in otherwise unlike provinces.

CLASSIFICATION OF IGNEOUS ROCKS.

From the foregoing considerations it is evident that if we attempted to classify igneous rocks on a basis of their groupings in petrographical provinces—that is, if we should unite in the first instance rocks that are said to be genetically related—we should separate in the system rocks of world-wide occurrence that are alike.

It must not be forgotten that igneous rocks are not like biological organisms, and that we are constantly misleading ourselves by the use of biological terms, such as generation, consanguinity, and family, into imagining that the relationships of various rocks should be treated like the relationships of organisms.

When we have had more experience in the synthesis and the differentiation of molten rock magmas in chemico-physical laboratories; have handled them like other solutions of salts, which have been studied at lower temperatures; have solidified them under diverse physical conditions, we shall no doubt free ourselves from the fascination of biology and look upon rocks as the chemist looks upon a solidified mass of mixed salts. Is it not possible, in the period of preparation of such properly equipped laboratories, to anticipate their psychological effects and to think of the study of igneous rocks, their magmas and relationships, as purely physico-chemical problems, involving the measurement and comparison of mass and force, and their definite quantitative expression?

It being evident from the diagrams that there are gradual transitions in the chemical composition of igneous rocks from one extreme to another, that there are no recognizable groupings of rocks or noticeable subdivisions of the chemical series, and that chemically similar rocks occur in genetically different families, it follows that the subdivision of all igneous rocks into groups for purposes of classification must be along arbitrarily chosen lines. And the intricate character of the chemical variations, apparent in the diagrams, prevents a simple quantitative statement of any possible limits which may be selected for subdivisions of the series, however arbitrarily chosen. A careful study of the diagrams will convince one of the truth of this statement. It is a problem involving at least seven variable factors, and in its exact statement still more. It is the problem of expressing quantitatively the chemical composition of solutions of mixed salts often containing identical elements. The most artificial method of statement would be to consider the elements regardless of the possible salts in solution. A less artificial method would seem to be one which takes into account the salts which may enter the solution or may separate from it. In rock magmas the salts in solution may properly be considered to have the composition of those minerals which separate and crystallize when the magmas solidify. But it is understood that salts in solution may become split up into molecules of simpler composition, may be partially dissociated into ions, and may be combined in more than one manner in the act of separating from solution under diverse conditions.

When it is remembered that igneous rocks are solidified and for the most part crystallized mixed solutions, the expression of their chemical composition in terms of the separated salts or minerals developed in them is eminently reasonable. These principles underlie the quantitative classification of igneous rocks proposed by Cross, Pirsson, Washington, and the author.

In expressing the chemical composition of the rocks in terms of the minerals developed it is advisable to reduce the complex possibilities by selecting the simpler and commoner minerals as standards of comparison. The details of the method must be learned from the published essay,^a to which the reader is referred if he is not already familiar with it.

CLASSIFIED DIAGRAMS.

The resulting chemical subdivision and grouping of igneous rocks by the method of quantitative classification recently proposed can be well shown graphically by the diagrams already described. The clearest exposition, however, requires a greater number of multiple diagrams than has been prepared, in order to separate all the divisions established by the classification. But the expense of publication has prevented the carrying out of such a plan, and so fewer multiple diagrams have been used, with a consequent loss of simplicity and a greater complexity than exists in the actual system of classification itself. The advantages to be derived from the exposition made, however, are sufficient to warrant its publication. It presents the salient features and results of the classification in a manner which can not be conveyed by words.

Multiple diagrams have been prepared to exhibit the grouping and variations in rocks belonging to the five classes of the quantitative system. Those of the first, second, and third classes are represented on three separate diagrams, while those of Classes IV and V are placed on one diagram because of their smaller number. The diagrams are presented in two forms—in one form spots represent the distribution of loci of analyses and their range of variation with respect to silica and alkalies; the other form is an individual diagram showing the variations with respect to the principal chemical components. (Pls. III, IV, V, VI, and VII.)

The distribution of the analyses belonging to the five classes, with respect to silica and alkalies, is shown by the spotted diagrams on Pls. III, IV, and V and by the differently colored spots in the composite diagram on Pl. I, in which the yellow spots belong to Class I, the red spots to Class II, the blue ones to Class III, and the black ones to Classes IV and V.

Since Class I is peralitic, that is, is extremely rich in silic minerals—quartz and aluminous feldspathic minerals—most of these rocks occur in the diagram near the curved lines showing the positions of rocks composed wholly of quartz with albite or orthoclase, and albite with nephelite, or orthoclase with leucite. But rocks of this class include all those rich in alumina, which may form anorthite, a nonalkalic mineral. Consequently they also occur in the diagram remote from the curved lines, approaching the locus of anorthite at 43.160, -0.0.

^a Quantitative classification of igneous rocks. Chicago, 1903. Also Jour. Geol., vol. 10, 1902.

Class II is dosalic, that is, dominantly salic. There are less feldspathic minerals and more ferromagnesian ones, and since the latter are mostly low in alkalis, rocks of this class occur in the diagram farther from the limiting alkali-feldspathic curves than those of Class I.

As Class III is still richer in ferric minerals and lower in alkalis, rocks of this class occur still more removed from the curves just mentioned. The same is true to a greater degree for rocks of Classes IV and V.

It is seen that the positions of these classes of rocks overlap one another more or less in the composite diagram on Pl. I, hence the confusion of individual diagrams in the large multiple diagram of Pl. I.

DIAGRAMS OF CLASS I.

Let us consider separately the diagrams of the different classes of rocks, beginning with Class I. The persalanes, represented by 412 individual diagrams, being characterized by preponderant salic minerals, are subdivided into nine orders, according to the proportions of quartz and feldspars and of feldspars and feldspathoids (lenads). The order highest in quartz, perquaric, is highest in silica, and that highest in lenads, perlenic, is lowest in silica. Consequently the nine orders follow one another from left to right in the multiple diagram (Pls. II and III). The limits of the orders may be shown graphically for extreme cases, and may be interpolated for intermediate ones. Owing to the difference in the molecular weight of sodium and potassium, the limits for orders based on quartz and soda-feldspar (albite) and on quartz and potash-feldspar (orthoclase) do not coincide. Further, the greater chemical difference between the soda-lenad, nephelite, an orthosilicate, and the potash-lenad, leucite, a metasilicate, causes a still wider divergence between the boundaries of the orders based on albite and nephelite on the one hand and on orthoclase and leucite on the other. That is to say, the limits between the nine orders of persalic rocks vary according as the alkalis in the rocks are soda or potash. This is shown by the diagram on Pl. II. The black lines nearly at right angles to the upper curve mark the limits of the nine orders for ideal rocks composed wholly of quartz, albite, anorthite, or of soda-nephelite, albite, anorthite. The red lines transverse to the upper red curve mark the limits of the nine orders for rocks composed wholly of quartz, orthoclase, anorthite, or of leucite, orthoclase, anorthite.

The division lines for soda orders start from points on the quartz-albite-nephelite curve situated where $q:ab::7:1$; $q:ab::5:3$; $q:ab::3:5$; $q:ab::1:7$; $ab:ne::7:1$; $ab:ne::5:3$; $ab:ne::3:5$; $ab:ne::1:7$, and run to points on the quartz-anorthite line and the anorthite-nephelite line where $q:an::7:1$; $q:an::5:3$; $q:an::3:5$; $q:an::1:7$; $an:ne::7:1$; $an:ne::5:3$; $an:ne::3:5$; $an:ne::1:7$. The same may

be said of the division lines for potash orders, substituting the names of orthoclase and leucite for those of albite and nephelite, respectively.

The diagram on Pl. II shows that the first four orders in each case nearly coincide, the boundary lines for potash rocks lying a little to the right of those for soda rocks. That is, the limit for each quaric order of potash rocks reaches a little lower silica than that for the corresponding orders of soda rocks.

The diagram also shows that the last four orders in each case differ more and more widely as they become more lenic. The range for the potash rocks is much more restricted than for the soda rocks, and the limits of orders for the potash rocks are higher in silica than for the corresponding soda rocks. This is because the potash lenad, leucite, is a metasilicate with 55.0 per cent SiO_2 , while the soda lenad, nephelite, is an orthosilicate with 42.3 per cent SiO_2 .

Since most rocks contain both soda and potash, the limits for the orders will occur between the extremes illustrated on Pl. II, varying with the ratio between soda and potash in each case. This explains the confused arrangement of the lenic orders in the upper right-hand portion of the diagram of persalic rocks on Pl. III.

In this diagram the number of the order of each rock is given by the first figure under its individual diagram. The number of the rang is given by the second figure. A study of these numbers will show that in the left-hand portion of the large diagram there is general concordance among the individual diagrams with respect to orders and rangs, except near the borders between orders, and between rangs. But in the right-hand upper portion of the large diagram there is great confusion of orders. It will be noted that where diagrams of different orders occur close together that with the higher number is the more potassic, other things being equal. The confusion would disappear if diagrams were constructed to exhibit the various sub-rangs. The correspondence between the distribution of the persalic rocks according to orders in the multiple diagram on Pl. III and the theoretical limits of the orders as shown on Pl. II is apparent. The orders form belts transverse to the curves which are the limits to ideally pure alkalic persalic rocks, namely, those consisting wholly of quartz, alkali-feldspars, or lenads.

As the wholly alkalic rocks occur along the limiting curves just mentioned and those free from alkali occur on the bottom line of the diagram, it follows that the various rangs of persalic rocks occur at intervals between these limiting lines; the peralkalic nearest the upper curves, the percalcic nearest the bottom line.

The boundary lines between the 5 rangs of persalic rocks are shown in the diagram on Pl. II. The black lines nearly parallel to the upper curve mark the limits for those based on soda alone; the red lines for those based on potash alone. Since most rocks contain both alkalies the limit for rangs will shift according to the ratio between soda and potash in the rocks. The rangs form belts roughly parallel to the limiting curves and bottom line of the multiple

diagram. The limiting lines are drawn from the point of pure quartz, where they all become zero, to points on lines marking the middle of the perfelic order, 5—that is, the lines for mixtures of albite and anorthite in the case of pure soda rocks, and that for mixtures of orthoclase and anorthite for pure potash rocks. The points on these lines occur in the first case where $\text{Na}_2\text{O}:\text{CaO}::7:1$; $\text{Na}_2\text{O}:\text{CaO}::5:3$; $\text{Na}_2\text{O}:\text{CaO}::3:5$; $\text{Na}_2\text{O}:\text{CaO}::1:7$. They occur in the second case where $\text{K}_2\text{O}:\text{CaO}::7:1$, etc. From these points the limiting lines pass to corresponding points on lines representing mixtures of nephelite and anorthite and of leucite and anorthite.

From Pl. II it is seen that the range of rangs is nearly concordant in the quaric orders of persalic rocks and more and more divergent in the more lenic orders according as the rocks compared are more sodic or more potassic. This explains the apparent confusions of rangs in the right-hand portion of Pl. III.

There is a close correspondence between the distribution of the persalic rocks according to rangs in the large diagram (Pl. III) and the theoretical limits of rangs shown in Pl. II. This is shown by the second figure under each individual diagram.

The diagram on Pl. II exhibits the limitations of orders and rangs of the persalic rocks containing lenads. These are seen at the right end of the diagram. The limiting lines representing combinations of nephelite and anorthite and of leucite and anorthite cut diagonally across the belts of orders and rangs. Thus in soda rocks whose limits are shown by black lines order 9 has only rang 1; order 8 contains rangs 1 and 2; order 7 embraces rangs 1, 2, and 3; order 6 has four rangs—1, 2, 3, and 4, while all five rangs occur in order 5. In potash rocks, represented by red lines, the conditions are not quite so simple, as is seen in the diagram. Each of the lenic orders has a little larger range in calcic content and includes a small amount of a more calcic rang than occurs in the purely soda rocks.

There are variations in composition in rocks not yet taken into consideration which further modify the distribution and arrangement of the individual diagrams. Most rocks contain femic components, and these are generally low in alkalies or free from them. With increasing amount of nonalkalic femic components the limits of rangs in the multiple diagram shift downward, for rangs are established on the ratio between salic alkalies and salic lime—that is, between the K_2O and Na_2O and the CaO in the standard feldspars and lenads. Consequently the more femic minerals present, the less salic, and the smaller the alkalies necessary to maintain a given ratio with diminished salic lime. Hence the boundary line between rang 1 and rang 2 occurs farther below the limiting quartz-feldspar lenad curves the greater the amount of nonalkalic femic components in rocks. This is evident on comparing rangs in Pls. III and IV.

In the majority of rocks in which there is more alumina than alkalies there is usually more lime than is sufficient to satisfy the excess of alumina, so that the ratio between salic alkalies and salic lime, which determines the rang, is dependent on the amount of alumina in the rock. From this it happens that rocks having like silica percentages and alkali-silica ratios, located near one another in the multiple diagram, may differ in rang because of differences in alumina. Other things being equal, those with higher alumina will have lower ratios between salic alkalies and salic lime; and conversely, those with lower alumina will have higher alkali-calcic ratios. And these differences may affect the rang of the rocks compared. Examples of this kind are more evident in diagrams of rocks of Class II, and are found at 56.3-0.065 and 56.7-0.066, also 56.6-0.074 and 56.9-0.074, on Pl. IV.

Where the femic components of persalic rocks are alkalic the rocks are always in peralkalic rang 1, so that the limit of rang 1 is extended downward in the multiple diagram. The individual diagrams for rocks of this kind are characterized by comparatively short Al_2O_3 lines, less than the sum of K_2O and Na_2O .

The effect of increasing amounts of femic components in persalic rocks upon the limits of orders is not so easily appreciated, the relations being less simple. If we compare two rocks with like silica and alkali percentages, which would occur near one another in the diagram (Pl. III), the more nonalkalic femic components the less salic; that is, the less alumina and the less anorthite. If the rocks are quaric the ratio between quartz and feldspar is increased by decreasing the anorthite feldspar. But the substitution of FeO , MgO , or CaO for Al_2O_3 would require more SiO_2 to form metasilicates than that required to form anorthite, consequently the free SiO_2 , quartz, would be reduced, but to a smaller amount than the feldspar is reduced, consequently the ratio between the quartz and feldspar would be higher in the rock with more nonalkalic femic components. The limits between the quaric orders would shift to the right.

If the rocks are lenic, containing nephelite, sodalite, or leucite, a reduction of anorthite feldspar would increase the ratio between lenads and feldspars. A substitution of FeO , MgO , or CaO for Al_2O_3 in amount equal to the CaO of presupposed anorthite would necessitate their conversion to metasilicates according to the method of the quantitative classification under discussion. This would require more silica than is required by anorthite, so that the amount of alkali feldspars would be reduced and the lenad-feldspar ratio further increased. In case the lime were replaced by magnesia and iron oxide and converted into orthosilicates there would be slight change in the silica available for the salic components, because of the general preponderance of magnesia in such rocks, and its lighter molecular weight and consequent greater number of molecules. Hence,

in most cases an increase of femic components would increase the lenad-feldspar ratio, and the limits between lenic orders of persalic rocks would shift toward the left.

In the less frequent cases in which alkali femic components occur, the limits between all orders shift to right or left according to the relative proportions of the alkali-femic components and according as they are acmite or are free from ferric iron.

The occurrence of magnetite, ilmenite and other mitic components also modifies the position of the ordinal limits, but in peralkalic rocks these constituents generally occur in such small amounts that their effects may be disregarded in the interpretation of the diagram under consideration.

With respect to subrangs it may be said that in the great majority of cases they can be recognized by a comparison of the yellow and green triangles representing the relative amounts of soda and potash in the rock. For in most instances all of the alkali is salic. In other cases where part of it is femic, the ratio between the salic alkalies can be made out by a scrutiny of the triangles and a comparison of the amounts of alkalies and alumina expressed by the lengths of the potash, soda, and alumina lines. The ratio in this case would be

$$\frac{K_2O}{Al_2O_3 - K_2O}.$$

In general, where alumina is in excess of the sum of the alkalies, a comparison of the triangles named, or of the lengths of the potash and soda lines, will determine the subrang to which the rock belongs. Those in which $\frac{K_2O}{Na_2O} > \frac{7}{1}$ are in perpotassic subrang 1; those with $\frac{K_2O}{Na_2O} < \frac{7}{1} > \frac{5}{3}$ are dopotassic subrang 2; when $\frac{K_2O}{Na_2O} < \frac{5}{3} > \frac{3}{5}$ the subrang is 3, sodipotassic; when $\frac{K_2O}{Na_2O} < \frac{3}{5} > \frac{1}{7}$ it is dosodic, subrang 4; and with $\frac{K_2O}{Na_2O} < \frac{1}{7}$ the subrang is 5, persodic.

These divisions apply only to the first three rangs. In the fourth rang, which is docalcic, there are only three subrangs, namely: 1, $\frac{K_2O}{Na_2O} > \frac{5}{3}$, prepotassic; 2, $\frac{K_2O}{Na_2O} < \frac{5}{3} > \frac{3}{5}$, sodipotassic; 3, $\frac{K_2O}{Na_2O} < \frac{3}{5}$, presodic. The fifth rang being precalcic, subrangs are not recognized.

A study of the diagrams on Pl. III shows that soda preponderates over potash in most persalic rocks; that sodipotassic rocks, subrang 3, are the most numerous; that dopotassic rocks are rare, and perpotassic ones extremely so. The numbers of rocks in the 5 rangs are 3, 31, 201, 156, 21.

Variations in the femic components, FeO, MgO, and femic CaO, are noticeable in the individual diagrams and represent differences among the subordinate mineral constituents of the rocks. Their quantity is so small that they may be neglected in the magmatic classification of these persalic rocks.

The diagrams plotted together demonstrate the gradual transition between orders of rocks of Class I, as well as between rangs and subrang. And since any individual diagram may represent a large body of igneous rock or a small facies of one, and since any of the diagrams may represent rock bodies of considerable importance, it follows that all parts of the series may be of equal importance geologically or petrologically, and consequently rocks that happen to belong on the border line of any set of subdivisions into which the whole rock series must be divided, for purposes of classification of any kind, may be as important as those situated at the center of such an arbitrary division, and in some regions it will happen that such rocks are the most important.

When the student has become convinced of the continuity of the chemical series of igneous rocks he will not be surprised to discover that a rock of great importance belongs on the boundary of a classificatory division, or probably falls on both sides of a division line. It will not affect the importance of the rock or militate against the value of the system of classification. It will simply be a "natural" fact. And the system of classification will appear to him as "natural" as any other system which attempts to classify igneous rocks.

DIAGRAMS OF CLASS II.

The multiple diagram of 335 dosalic rocks of Class II (Pl. IV) may be readily interpreted by comparison with that of Class I (Pl. III). The spotted diagram to the left shows the distribution of the analyses with respect to silica and alkalies. The rocks are for the most part lower in alkalies than those of Class I, because the femic components are generally nonalkalic. The few cases with rather high alkalies contain acmite molecules, which fact is indicated in the individual diagrams by pronounced iron oxide and soda and by low alumina. Several of these occur in the left-hand part of the multiple diagram at 74.35-0.092, 69.02-0.121, etc.

The dominant constituents in dosalic rocks being the same as those in the persalic rocks, nine orders have been established, in the same manner as in Class I. Rang and subrang also correspond to those in Class I. So there is the same general arrangement of individual diagrams in Pl. IV, according to orders and rangs, as in the multiple diagram of Class I, with the modifications produced by increasing amounts of femic components, for the most part nonalkalic. The belts of orders are transverse to the limiting quartz-alkali-feldspar lens curves. The limits of

rangs are lower than in the diagram of Class I. There is the same confusion of orders and rangs along the division lines consequent upon variations in alumina and femic components, and a like diversity of alkalies, shown by the yellow and green triangles, with a strong preponderance of soda over potash. The greatest number of rocks are dosodic. The numbers in each rang are: 0, 17, 126, 183, 9.

With an increase in the femic components the variations in iron oxide, magnesia, and lime become more noticeable and important, and it is necessary to recognize distinctions among the subordinate femic components, that is, to note grads and subgrads. The nature of the grads can not be determined directly from the diagrams because it depends on the amount of available silica, which may be combined with femic bases to form silicates, pyroxene, olivine, or akermanite, and also on the amount of ferric oxide and titanium oxide. The ferric oxide is blended with ferrous oxide in the diagrams and is not indicated graphically. Titanium oxide is so small in most dosalic rocks that it is not introduced into the diagrams in this Class II.

It is to be noted, however, that the silica is sufficiently high to form silicates of almost all the femic bases, and ferric oxide is in most cases low, so that the great majority of dosalic rocks belong to the prepolic grad 1, that in which the femic silicates—pyroxene and olivine—preponderate over the femic nonsilicates—magnetite, hematite, ilmenite, rutile, and the silico-titanate, titanite.

As to the subgrad to which these rocks belong, by far the largest number contain nonalkalic femic components, and therefore fall in the premirlic subrang 1. A small number contain alkalic femic components in nearly the same proportions as nonalkalic ones, and fall in the alkalimirlic subrang 2. Some, characterized by highly alkalic femic constituents, such as acmite, belong to subrang 3.

The multiple diagram for Class II (Pl. IV) exhibits similar transitions between orders and between rangs as those shown by the diagram for Class I, and permits the same conclusions to be drawn from it. The chemical series will appear more and more complete as more varieties of rocks are analyzed.

DIAGRAMS OF CLASS III.

The chemical relations of the salemic rocks, Class III, are expressed graphically on Pl. VI. Two of them are so high in silica that they have been plotted on Pl. IV with rocks of Class II. One is rockallose, with 73.60 SiO_2 , 0.091 $\frac{\text{alk.}}{\text{SiO}_2}$. It is intermediate between Classes III and II. The other is a pantellerite, with 68.75 SiO_2 , 0.144 $\frac{\text{alk.}}{\text{SiO}_2}$. It is also intermediate between Classes III and II.

The distribution of the rocks with respect to silica and alkalies is shown in the upper diagram of Pl. V. The location of the analyses in the multiple diagram is still farther from the limiting curves than in Class II, and the silica

ranges lower. The alkali-silica ratios reach high values in some cases. TiO_2 is present in notable amount in a number of instances.

It will be observed that the lower half of the individual diagrams is the larger in nearly every case, but the long, narrow, upper triangles indicate that there is more alumina than alkalies, and that part of the lime is salic, so that the salic components are more nearly equal to the femic than appears at first glance.

There are but two rocks in quarfelic order 3, those mentioned above, and plotted on Pl. IV. Very few occur in order 4. The greatest number are perfelic, order 5, and the lenic orders are well represented.

Most of the perfelic rocks are alkalicalcic, rang 3, or docalcic, rang 4. The few that are peralkalic or domalkalic are low in alumina, as, for example, 54.2–0.160 and 45.2–0.085. It is noticeable also in the lenic salemanses, orders 6, 7, 8, and 9, that the domalkalic character of the salic minerals in a number of rocks is due to low alumina rather than to high alkalies, as 50.00–0.110, 46.00–0.121, and 42.7–0.139.

There are great variations in the shapes of the diagrams of rocks nearly alike in silica and alkali-silica ratio. A few rocks are rich in potash, notably those from Leucite Hills, Wyoming, 54.08–0.163, and others. A greater number are rich in soda, occurring in the upper part of the multiple diagram. But the majority are sodipotassic and dosodic.

Since in these rocks the femic minerals are equal or nearly equal to the salic, and in some cases are more abundant, they are as characteristic of the rocks as the salic minerals. The salemanses differ considerably with respect to these constituents, which is plainly shown by differences in the shapes of the lower part of the individual diagrams. Some are long in the direction of lime; others long in magnesia. Few have more iron oxide than magnesia. From this it follows that the grad, subgrad, and section of subgrad are as important in the classification of these rocks as are order, rang, and subrang.

The grad of these rocks can not be determined from the diagrams because it depends upon the proportions of ferromagnesian silicates and nonsilicates determined by the available silica and the ferric iron not allotted to acmite.* It is to be remarked that the great majority of salemic rocks included in the diagrams are dopyric, grad 2—that is, normative pyroxene and olivine dominate over magnetite, hematite, and ilmenite. In most of these rocks there is a notable amount of normative nonsilicates. The majority of these rocks are perpyric or dopyric, sections 1 and 2—that is to say, normative pyroxene preponderates over olivine.

The character of the subgrad is indicated by the diagrams, since this depends upon the proportion of alkalies that enter the femic minerals. With few excep-

tions the alumina is greater than the sum of the alkalies, so that the femic minerals are nonalkalic and the rocks belong to the permirlic subgrad 1. The exceptions to this are the two rocks rich in acmite—rockallose and the rock near varingose.

The diagrams also show that most of these salemans are domiric, section 2, ferrous oxide and magnesia dominating over femic lime. This, however, is not perfectly evident in the diagrams because of the lack of information concerning ferric iron and the necessity of deducting salic lime from the total lime.

Finally, when it is remembered that nearly half the molecules of iron oxide belong to ferric oxide, the diagrams show that in most cases the rocks are domagnestic, subsection 2, with magnesia dominant over ferrous iron. In a few instances they are permagnestic, which is indicated by long, narrow, blue triangles.

DIAGRAMS OF CLASSES IV AND V.

The diagrams of dofemic and perfemic rocks, Classes IV and V, are plotted together on Pl. VII. This has been done because of the comparatively small number of analyses of these rocks at hand and the desire to economize space. The distribution of these rocks with respect to silica and the alkalies is shown in the lower diagram on Pl. V. As should be expected, these rocks are far from the quartz-alkali-feldspathic curve, are low in alkalies, and extend to the lowest limit of silica. The diagram of one rock comparatively high in alkalies falls outside the area of Pl. VII, and is not represented. The rock is a nephelite-basalt from Katzenbuckel, Odenwald (45.04–0.209). Individual diagrams belonging to rocks of Classes IV and V are designated by Roman numerals, IV and V, before Arabic ones denoting orders and sections of orders.

The arrangement of the individual diagrams in the multiple one is in accord with the general system adopted with special reference to the great majority of rocks, the more salic ones. The rocks of Classes IV and V are less than one-tenth of all that are represented in the diagrams. Their arrangement is related to one component of prime importance, silica. But alkalies are extremely subordinate and would not properly be chosen as a basis for their coordination were these rocks considered by themselves. However, their relations to the more salic rocks are exhibited by retaining the same system of arrangement.

The chief difference between the rocks of Classes IV and V lies in the amount of alumina, with which in general there is sufficient lime or alkalies to form salic feldspars or lenads. In one case only is the composition of the magma such as to require the assumption of salic corundum, the rock being magnetite-spinelite from Routivare, Sweden (4.08–0.092). Most all of the rocks containing alkalies belong to Class IV, but this class also embraces rocks without alkalies, the diagrams occurring

on the zero line for alkali-silica ratios. Nearly all the rocks of Class V are so low in alkalis as to occur on the zero line. The higher ratios obtaining in several iron ores with 4 to 8 per cent of silica may easily be due to errors in chemical analysis, though, of course, they may be correct values.

Since dofemic and perfemic rocks are divided into orders according to the relative proportions of femic silicates and nonsilicates, and into sections of orders according to the proportions of femic metasilicates and orthosilicates, it follows that the five orders and sections range according to the silica content of the rock from perpolitic order 1, perpyritic section 1, with highest silica, 55.5, to permitic order 5, with lowest silica, 0.7. In like manner the various sections under each order range from higher to lower silica. These distinctions do not appear in the shapes of the diagrams, but in their lateral position in the multiple diagram.

With respect to rangs it happens that without exception all the rocks represented in this collection of analyses belong to permirlic rang 1, the alkalis which occur in the rocks being salic, which is shown in the diagrams by the alumina line exceeding the sum of those of the alkalis.

Sections of rangs and subrang are based on the proportions of femic lime, magnesia, and ferrous oxide, but the proportions of ferrous and ferric oxide are not indicated in the diagrams. It is to be noted, however, that iron is generally subordinate to magnesia in most perfemic rocks with more than 28 per cent of silica, so far as they are represented in the collection of analyses; and when it is remembered that a part of this iron is ferric, it will be seen that the proportion of ferrous iron is smaller than appears in the diagrams.

While the lime is considerable in a large number of cases, it is very small in many of the rocks, and when salic lime is deducted it is found that the femic lime is subordinate to the magnesia and ferrous iron in nearly every instance. A majority of the dofemic rocks, Class IV, are domiric, section 2 of rang 1. A smaller number are permiric, section 1 of rang 1. In nearly every case these rocks are domagnesian, subrang 2. The iron ores of Class IV are perferrous, subrang 5.

The perfemanes, Class V, with the exception of the iron ores, are permiric and domiric in about equal numbers. Lime is subordinate to magnesia and iron. They belong to sections 1 and 2 of rang 1. In nearly every case these rocks are permagnesian, subrang 1. This is shown by the elongation of the magnesia line. The iron ores of course are perferrous, subrang 5. The abrupt change from the titaniferous iron ores, below 27 per cent silica, to the magnesium-rich rocks above this percentage of silica is very noticeable. It indicates that the transitional rocks which have been described by petrographers have

The diagrams of the different classes of igneous rocks established by the quantitative system illustrate the chemical characters of the rocks grouped together by this system, and show the degrees of similarity and the ranges of variation within the different divisions of the classification so far as they exist in the rocks represented by the 977 analyses in the collection.

A greater number of multiple diagrams representing separate divisions of the system will give more definite graphic expression to these minor groups of rocks. Their preparation and publication at this time have not been feasible. It is possible, also, to devise individual diagrams which shall express more or less definitely the norm of each rock, but these would of necessity be so intricate that a larger scale of drawing would be required, entailing serious difficulties of publication.

It is believed that the simpler individual diagrams and more composite multiple ones here presented will serve a better purpose at this time in demonstrating graphically some of the chemical facts and relationships that have been used by Cross, Pirsson, Washington, and the author as the foundation on which they have constructed the quantitative system of rock classification.

CORRELATION OF IGNEOUS ROCKS CLASSIFIED BY THE QUANTITATIVE AND QUALITATIVE SYSTEMS.

The classified list of rocks already given shows the character of the correlation that may be made of the two systems of classification. The variety of names that appear within any one of the more common divisions of the quantitative systems is due in part to differences in chemical composition, which are recognized by subdivisions of the system of a lower order, as grad and subgrad. It is in part due to diversity of texture and mineral development, which is expressed in this system by terms qualifying the magma names. But it is also due to a great extent to essential differences in the bases of classification in the two systems and to the flexibility of qualitative definitions.

A brief tabulated statement of the salient features of the correlation is given, with some general remarks concerning the more common relationships. Greater detail must be gotten from the classified list and from the collection of rock analyses published by Washington.

CLASS I. PERSALANE.

1. Victorare.	2. Belgare.	3. Columbare.	4. Britannare.	5. Canadare.	6. Russare.	7. Tasmanare.	8. Ontarare.	9. —.
Quartz-veins.	Quartz-pegmatite.	Granite.			Nephelite-syenite.			Nephelite-pegmatite.
	R. 1. Dargase.	R. 1. Alaskase.	R. 1. Liparase.	R. 1. Nordmarkase.	R. 1. Miskase.	R. 1. Langenase.	R. 1. —.	R. 1. —.
	Quartz-pegmatite.	Aplite. Granite. Alaskite. Tordrillite. Quartz-porphyre. Quartz-keratophyre. Rhyolite. Obsidian.	Aplite. Granite. Quartz-syenite. Syenite-porphyre. Gronudite. Quartz-pantellerite. Rhyolite. Falsanite. Comendite. Quartz-keratophyre. Obsidian.	Syenite. Quartz-syenite. Neph-syenite. Nordmarkite. Pulaskite. Umpeckite. Albitite. Solvsebergite. Keratophyre. Bostonite. Trachyte. Phonolite.	Neph-aplite. Neph-syenite. Foyaitite. Ditrolite. Muscite. Mariupolite. Tingualite. Heronite. Phonolite. Leucite-phonolite.	Foyaitite.	R. 1. —.	Neph-pegmatite.
	R. 2. Alabachase.		R. 2. Toscanase.	R. 2. Pulaskase.	R. 2. Vizezenase.			
	Aplite. Granite. Alabachite. Rhyolite.		Aplite. Granite. Quartz-monzonite. Granodiorite. Diorite. Syenite. Quartz-syenite-porphyre. Rhyolite. Toscanite. Latite. Dellenite. Dacite. Trachyte. Andesite.	Quartz-syenite. Neph-syenite. Pulaskite. Nordmarkite. Laurvikite. Sodalite-syenite. Diorite. Bostonite. Rhomben porphyre. Vulskite. Keratophyre. Trachyte. Leucite-trachyte. Andesite.	Neph-syenite. Neph-rhomben porphyre. Neph-tingualite. Tingualite.			

CLASS I. PERSALANE—Continued.

1. Victorare.	2. Belgare.	3. Colambare.	4. Britannare.	5. Canadare.	6. Benare.	7. Tasmanare.	8. Ontare.	9. —.
Quartz-veins.	Quartz-pegmatite.	Granite.	Granite.	Syenite, anorthosite.	Nephelite-syenite.	Nephelite-pegmatite.		
		R. 3. Roccenare. Granite. Quartz-diorite-porphyr. Toscanite. Vulcanite.	R. 3. Coloradare. Granite. Granodiorite. Quartz-diorite. Bastardite. Diorite. Dacite. Andesite. Trachyte.	R. 3. —. Syenite. Diabase-porphyr. Andesite.				
				R. 4. Labrador- asc. Anorthosite.				
				R. 5. Canadare. Anorthosite.				

CLASS II. DOSALANE.

1. —.	2. —.	3. Hispanare.	4. Austrare.	5. Germanare.	6. Norgare.	7. Italar.	8. Campanare.	9. Lappare.
		Granite and quartz-diorite.		Syenite, diorite, gabbro.	Nephelite, syenite, and essexite.		Leucite-basanite.	Urtite.
		R. 1. Varlagase. R. 1. Pantellerase. Gronudite. Pantellerite. Felsite.		R. 1. Umptekase. Syenite. Nordmarkite. Umptekite. Hedrumite. Neph.-syenite. Heumite. Trachyte. Sodalite-trachyte. Leucite-trachyte.	R. 1. Laurdalase. Neph.-syenite. Leucite-neph.-syenite. Pseudoleucite-syenite. Laurdalite. Syenite. Hedrumite. Tingualite. Leucite-tingualite.	R. 1. Lajavrase. Lajavrite. Chibinite. Allochettite. Neph.-porphyry. Tingualite. Leucite-tingualite.	R. 1. —. Soda sussexite. Tingualite. Leucitite.	R. 1. Urtase. Urtite. Ijolite. Arkite.
		R. 2. Dacase. Granite. Quartz-diorite. Syenite. Dacite. Andesite. Trachyte-andesite.		R. 2. Monzonase. Syenite. Pulaskite. Monzonite. Durbachite. Neph.-syenite. Ditroite. Essexite. Granite. Diorite. Kersantite. Minette. Climinite. Akerite. Shoshonite. Banakite. Trachyte. Leucite-trachyte. Leucite-phonolite. Andesite. Basalt.	R. 2. Essexase. Neph.-syenite. Neph.-monzonite. Laurdalite. Essexite. Monzonite. Shonkinite. Covite. Borolanite. Heumite. Monchiquite. Theralite. Kulalite. Leucite-kulalite. Tephrite. Neph.-felsite.	R. 2. Vulturase. Leucite-tephrite. Basanite. Leucitite. Hedynophyre.	R. 2. Vesuvase. Leucite-basanite.	

CLASS II. DOSALANE—Continued.

1. —	2. —	3. Hesperare.	4. Austrare.	5. Germanare.	6. Norgare.	7. Halare.	8. Campanare.	9. Lappare.
		Granite and quartz-diorite.	R. 3. Tonalase. Granite. Quartz-monzonite. Granodiorite. Quartz-diorite. Tonalite. Quartz-norite. Syenite. Diorite. Dacite. Latite. Andesite. Trachyte. Dolerite.	Syenite-diorite. gabbro. R. 3. Andase. Syenite. Monzonite. Diorite. Gabbro. Norite. Essexite. Beerbachite. Mondhaldeite. Kersantite. Andesite. Latite. Vulcanite. Climinite. Shoshonite Banakite. Quartz-basalt. Basalt. Dolerite. Olivine-diabase. Leucite-monzon-chil-quite. Neph-tephrite.	Nephelite, syenite, and essexite. R. 3. Salemase. Diorite. Gabbro. Essexite. Basalt.	R. 3. — Leucite-tephrite.	Leucite-basaltite.	Urdite.
		R. 4. — Quartz-diorite.	R. 4. Bandase. Tonalite. Diorite. Andasite. Quartz-basalt.	R. 4. Hesperare. Diorite. Monzonite. Anorthosite. Gabbro. Corrite. Andesite. Basalt. R. 5. Cornase. Diorite. Olivine-gabbro.	R. 4. — Diorite. Gabbro.			

CLASS III. SALKEMANE.

1. —	2. —	3. Atlantare.	4. Vaalare.	5. Gallare.	6. Portugare.	7. Kameranare.	8. Bohemare.	9. Flannare.
				Diorite and gabbro.		Lampophyre and leucite-nephelinite lavas.		
		R. 1. Rockallite. Pantellerite.		R. 1. Oreadase. Oreadite. Wyomingite.	R. 1. Wyomingase. Shonkinite. Camptonite. Nephelinite. Analcite-basalt.	R. 1. Malignase. Malignite. Therallite. Ijolite-porphyr.	R. 1. Chotase. Leucitite.	R. 1. Ijolase. Madupite. Ijolite. Nephelite-porphyry. Neph.-basalt.
				R. 2. Kilanase. Shonkinite. Syenite-lamprophyre. Mica-picrophyre. Abeorokite. Basalt. Augitite.	R. 2. Monchiquase. Shonkinite. Leucite-syenite. Monchiquite. Vogedite. Tephrite. Leucite-basanite. Leucite-basalt. Nephelite-basalt. Limburchite.	R. 2. Kameranase. Heumite. Therallite. Monchiquite. Farrisite. Leucite-basalt. Leucite-nephelinite. Hattynophyre. Basalt.	R. 2. Albanase. Ijolite. Nephelinite. Leucitite. Therallite. Leucite-tephrite. Limburchite.	
			R. 3. Vaalase. Quartz-gabbro. Olivine-diabase. Basalt.	R. 3. Camptonase. Kentallenite. Olivine-monzonite. Diorite. Gabbro. Essexite. Camptonite. Abeorokite. Leucite-basanite. Neph.-basalt. Quartz-basalt.	R. 3. Limburchase. Neph.-gabbro. Ijolite. Camptonite. Monchiquite. Hornblende-basalt. Neph.-basanite. Limburchite. Augitite. Hornblendite.	R. 3. Etindase. Camptonite. Neph.-basalt.		

CLASS IV. DOFEMANE.

1. Hungare.	2. Scotare.	3. Sverigare.	4. Adirondackare.	5. —.
Gabbro and peridotite.			Iron ores.	
S. 1. Minnesotiare. Gabbro. Wehrlite. Pyroxenite.	S. 1. —. Augite-norite. Pyroxenite. Neph.-basalt.	S. 1. Bergenlare. Ilmenite-norite.		
S. 2. —. Gabbro. Missourite. Wehrlite. Peridotite.	S. 2. Paoliare. Gabbro. Koswite. Jacupirangite. Augite-peridotite. Hornblende-basalt. Neph.-basalt.	S. 2. —. (?) Pyroxenite. Avezacite. Neph. melillite-basalt.	S. 2. Adirondackore. Iron ore.	S. 2. —. Iron ore.
S. 3. Hungariare. Wehrlite. Peridotite. Hornblende-picrite. Hornblendite. Lherzolite.	S. 3. Texiare. Peridotite. Neph.-basalt. Neph. melillite-basalt.		S. 3. Champlainore. Iron ore.	
S. 4. —. Peridotite. Lherzolite.	S. 4. —. Limburgite. Neph.-melillite-basalt.			
S. 5. Pyreniare. Hornblende-peridotite. Hornblende-lherzolite. Venanzite.	S. 5. —. Mica-peridotite.			

CLASS V. PERFEMANE.

1. Maorare.	2. —.	3. —.	4. —.	5. —.
Peridotite and pyroxenite.		Iron ores.		
S. 1. Carolinlare. Websterite. Pyroxenite. Lherzolite.				
S. 2. Marylandiare. Pyroxenite. Koswite.	S. 2. —. Lherzolite.		S. 2. —. Iron ore.	S. 2. —. Iron ore.
S. 3. —. Koswite.				S. 3. —. Iron ore.
S. 4. —. Saxonite.		S. 4. —. Iron ore.		
S. 5. Maoriare. Dunite. Harzburgite.	S. 5. —. Dunite sidéronitique.			

Approaching the subject from the standpoint of the qualitative, mineralogical system we are interested in the distribution of rocks in the quantitative system in the first instance according to their content of quartz, feldspar, feldspathoid, or ferromagnesian minerals. We may consider the distribution of, first, rocks containing a notable amount of quartz and their equivalent lava forms; second, rocks characterized by feldspar without notable amounts of quartz or feldspathoids; third, rocks containing notable amounts of feldspathoids; fourth, rocks composed chiefly of ferromagnesian minerals.

In general, it may be said that the quartzose igneous rocks fall almost without exception in Classes I, II, and III, and those in Class III are comparatively rare, so that most quartzose rocks belong to Classes I and II, and those with notable amount of quartz ($\frac{Q}{F} > \frac{1}{7}$) are in orders 4 and 3, very few occurring in orders 2 and 1, and these only in Class I.

Nearly all rocks known as granite, granodiorite, quartz-monzonite, quartz-diorite, and the rare quartz-gabbros, together with their aphanitic and glassy equivalents, belong to order 4, Classes I and II, in most part, and to some extent to order 3 in Class I, very few being found in this order of Class II. The most quartzose rocks belong to Class I.

Of the minerals associated with quartz the most abundant and frequent are feldspars, usually preponderant, and these are distinguished in the qualitative system as alkalic, alkalicalcic, and calcic. Since it is generally true that as magmas are richer in magnesium and iron they also contain more calcium, it follows that rocks richer in ferromagnesian minerals usually carry more calcic feldspars than rocks poor in those minerals. Consequently the greater number of quartzose rocks with alkalic feldspars occur in Class I, and the greater number with calcic feldspars are in Class II; and those with the most calcic feldspar should occur in Class III. To this, of course, there are notable exceptions, especially where the feldspar mineral is not ferromagnesian but alkalic, as aegirine, in rockallose.

Most granites are found in Class I, and most of these are in order 4, with dominant feldspars; fewer in order 3. Most of these granites are peralkalic and subalkalic, rangs 1 and 2. But in order 4 a considerable number are alkalicalcic, rang 3. The more alkalic rocks are commonly sodipotassic, while the alkalicalcic ones are mostly dosodic; that is, with increase of lime there is a diminution of potash.

These quartz-bearing granites include rocks that have been named aplite, granite, granitite, granodiorite, quartz-monzonite, quartz-diorite, the phanerocrystalline porphyries of these, and quartz-porphyry, rhyolite, dacite, and andesite, together with those of special varieties—alaskite, albitite, tordrillite, comendite,

paisanite, toscanite, and others. Some rocks that fall within the limits of these divisions of the quantitative system bear names occurring mostly in other divisions, such as syenite, nordmarkite, diorite, andesite. These are in part intermediate rocks deserving double magma names; in part, those, like some andesites, whose mineral composition is not completely determinable, and in which the quartz content is obscure or uncrystallized.

A much smaller number of granites belong to Class II, dosalanes. The most alkalic members of this class, pantellerite and grorudite, are comparatively rich in ferric oxide.

Most of the quaric rocks of Class II are alkalicalcic and dosodic. The greater number of them bear the names quartz-diorite, diorite, and andesite.

The quaric rocks in Class III are low in quartz, except in the rare varieties of pantellerite and rockallite. But in the other rocks, also rare, quartz occurs in small amount with alkalicalcic feldspars and calcic feldspars. One of these rocks is quartz-gabbro, another a diorite, and several others olivine-bearing rocks, whose chemical analyses are such that they fall in order 4 of this class.

Rocks characterized by feldspars without notable amounts of quartz or feldspathoids occur in perfelic order 5 of Classes I, II, and III.

Among the perfelic persalanes, Class I, the more alkalic rocks are commonest (syenites), alkalicalcic ones are rare, while docalcic ones are well known (anorthosites). As to the character of the alkalies, soda preponderates in most cases, dosodic rocks being more abundant than sodipotassic ones, which, however, are common.

The names borne by these rocks are: Syenite, nordmarkite, pulaskite, laurvikite, bostonite, trachyte, vulsinite, andesite, keratophyre, and others. The most sodic rocks have been called albitite; the most calcic, anorthosite. Some of them have been called nephelite-syenite, phonolite, leucite-trachyte, and other names.

The perfelic dosalanes, Class II, are more common than the extremely feldspathic persalanes, and the alkalicalcic ones are more numerous than the domalkalic or docalcic forms, but these are also well represented. Most of these rocks are dosodic, although many are sodipotassic.

They appear under the names of syenite, umptekite, monzonite, diorite, gabbro, norite, trachyte, ciminite, akerite, shoshonite, andesite, basalt, and others. They also include some rocks called granite, nephelite-syenite, leucite-trachyte, and kersantite.

The perfelic selfemanes, Class III, are alkalicalcic and docalcic, and most of them are dosodic. They embrace gabbro, norite, ariegite, kedabekite, camp-tonite, dolerite, and basalt. The more potassic and sodipotassic rocks of this class and order have been called kentallenite, absarokite, and lamprophyre. A

few peralkalic rocks belonging here occur at Leucite Hills, Wyoming—orendite, wyomingite.

The rocks characterized by notable amounts of feldspathoids or lenads—leucite, nephelite, sodalite—with the exception of a few that belong in Class IV, fall within the lenic orders 6, 7, 8, 9 of Classes I, II, and III.

Lenic persalanes, Class I, are most abundant in order 6, with dominant feldspar, but they are known in each of the more lenic orders. They are mostly peralkalic and dosodic, some being sodipotassic. They have been named nephelite-syenite, foyaite, ditroite, miascite, phonolite, and tinguaita. Very few contain leucite.

The same is true for the lenic dosalanes, Class II. Most of them occur in lendofelic order 6, but the other lenic orders are represented.

In order 6 they are mostly peralkalic and domalkalic, and the majority are dosodic. They include nephelite-syenite, laurdalite, essexite, tinguaita, theralite, and others, besides some rocks called syenite, monzonite, diorite, and gabbro.

Rocks of the remaining orders are peralkalic and dominantly sodic. A few rocks in order 7 are sodipotassic.

Order 7 contains rocks called lujavrite, tinguaita, tephrite, leucitite, hauynophyre, and others.

Rocks of orders 8 and 9 are rare. The first embrace leucite-basanite, leucitite, and tinguaita. The ninth order is represented by urtite, an ijolite rich in nephelite, and sodipotassic arkite.

Lenic salfemanes, Class III, are about as numerous as lenic rocks in Classes I and II. They are more uniformly distributed through orders 6, 7, and 8. Perlenic rocks, order 9, are rare.

In order 6 there are more alkalicalcic rocks than in the corresponding order of Class II. Most of the rocks are sodipotassic and dosodic. The rocks have been called shonkinite, leucite-syenite, leucite-monchiquite, monchiquite, limburgite, basanite, and others.

In order 7 the rocks are dominantly alkalic and dosodic. They embrace malignite, theralite, nephelite-basalt, nephelinite, and others.

Order 8 is similar to order 7. The rocks are rarer and a few are dopotassic. They are theralite, ijolite, nephelinite, leucitite, and others.

The rocks of order 9 are peralkalic, and include dopotassic madupite of Leucite Hills, Wyoming, and dosodic ijolite, nephelite-porphry, and nephelite-basalt.

Rocks with preponderant femic constituents, the dofemanes, Class IV, and perfemanes, Class V, are distinguished from one another by the presence in the former of a notable but subordinate amount of salic, feldspathic minerals and

by their absence from the perfermanes. The dofemanes, then, contain either notable subordinate amounts of feldspar, leucite, nephelite, sodalite, or of aluminous ferromagnesian, alferric minerals.

In Class IV the five orders, based on the proportions of normative pyroxene and olivine, compared with magnetite, ilmenite, and other nonsilicates, are all represented. Orders 1 and 2 are most common. In each of these the more pyroxenic sections are better represented than the more olivinic. The rocks invariably belong to the permirlic rang, 1; that is to say, the femic minerals contain little or no alkali. In most cases ferrous oxide and magnesia preponderate over lime, and in the majority of rocks magnesia dominates over ferrous oxide.

In perpolitic order 1 the rocks are known in the qualitative system as gabbro, olivine-gabbro, norite, koswite, peridotite, pyroxenite, jacupirangite, nephelite-basalt, nephelite-melilite-basalt, and limburgite.

In polmitic order 3, with nearly equal silicate and nonsilicate minerals, the few rocks as yet described have been called ilmenite-norite, pyroxenite, avezacite, and nephelite-melilite-basalt.

Orders 4 and 5, with preponderant magnetite and ilmenite, embrace certain feldspathic iron ores from Sweden, Canada, and New York State.

Rocks of Class V are comparatively rare; they have little or no feldspathic minerals or aluminous ferromagnesian minerals. Most rocks belong to perpolitic order 1, and range from wholly pyroxenic to wholly olivinic kinds. A very few rocks fall within each of the other orders.

In order 1 the rocks have been called pyroxenite, websterite, koswite, peridotite, saxonite, harzburgite, and dunite.

In order 2, with notable, subordinate, nonsilicate minerals, occur a lherzolite, and dunite rich in iron ore.

In the other orders, 3, 4, and 5, the rocks are titaniferous iron ores, with variable amounts of ferromagnesian silicates. In one instance the rock consists of magnetite and spinel

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CONTRIBUTIONS TO THE GEOLOGY OF WASHINGTON

Geology and Physiography of Central Washington

By GEORGE OTIS SMITH

Physiography and Deformation of the Wenatchee-Chelan District
Cascade Range

By BAILEY WILLIS



WASHINGTON
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CONTRIBUTIONS TO THE GEOLOGY OF WASHINGTON

GEOLOGY AND PHYSIOGRAPHY OF CENTRAL WASHINGTON

BY

GEORGE OTIS SMITH

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GEOLOGY AND PHYSIOGRAPHY OF CENTRAL WASHINGTON.

By GEORGE OTIS SMITH.

INTRODUCTION.

Central Washington includes a part of two great topographic provinces, the great plain of the Columbia and the Cascade Range. The former, in its position and general desert-like character, suggests at once a resemblance to the Great Basin of Utah and Nevada; and the vastness of the desert plain is emphasized by the snowy peaks of the Cascades along its western border. These provinces are not to be regarded as unconnected in their geologic history, however great the contrast in their general features. The intermediate zone between the great plain on the east and the mountain range on the west is a strategic point for the investigation of the geologic structure and history and the interpretation of the present topography of both provinces. On the extensive basalt-covered plain monotony wearies the traveler, while on the rocky peaks of the Cascades the complexity taxes the powers of the observer.

Yakima River, an important tributary of the Columbia, drains a large area on the eastern slope of the Cascade Mountains, and in the medial portion of its course this river traverses a region which shares many of the features belonging to the two provinces mentioned above. The Mount Stuart and Ellensburg quadrangles^a are situated close to the geographic center of the State of Washington and include an area of about 1,600 square miles. In the southern portion of this area the country is characterized by broad valleys and low, gently sloping ridges. The general absence of forest trees and the abundance of the sagebrush are other features that remind the traveler of the great plain to the east. In the northern part of the Mount Stuart quadrangle the ridges are of a bolder type and the extremely rugged topography of Mount Stuart and other portions of the Wenatchee Mountains suggests at once the main range of the Cascades. These two quadrangles have been surveyed both topographically and geologically, and the results of these surveys constitute the basis of the present paper.

^a Under the plan adopted by this survey for the preparation of a geologic map of the United States the entire area is divided into small quadrangles, bounded by certain meridians and parallels, and each is named from some well-known place or feature appearing in it.

In the preparation of this paper I have had the privilege of frequent conference with Mr. Bailey Willis. His familiarity with the area here described has given special value to his helpful criticism, which is gratefully acknowledged. Portions of the area described by Mr. Willis have also been visited by myself, and I believe the conclusions reached in his paper to be in general agreement with the results of the work in central Washington. The separation of the two areas and the fact that the field work was more or less distinct and conducted under different conditions led to the publication of our results as two papers, rather than as a joint contribution to the geology of the region. In the mapping of the Ellensburg quadrangle I was assisted by Mr. Frank C. Calkins.

The results of this survey have been published in the Ellensburg folio, No. 86, of the Geologic Atlas of the United States.

LITERATURE.

A glance at the literature which is available regarding this area will serve to show the present state of our knowledge of the geology and physiography of central Washington. Russell^a records the occurrence of older crystalline rocks in this area, separated by an unconformity from overlying sediments of early Tertiary age. Above these, with another unconformity, is the great series of lava flows, named by Russell the "Columbia lava,"^b above which is another sedimentary series of Miocene age, correlated by Russell with the John Day beds of Oregon. Professor Russell's determination of the age of the Cascade Range as post-Miocene^c is provisional only, but the antecedent character of the main streams of the region is more definitely stated, as follows:

"The evidence that the main drainage lines of central Washington were established before the present relief was initiated is cumulative and abundant. The rivers began to flow when Lake John Day was drained and had their courses determined by the slope of the surface of the bottom of the old lake. Since then mountain ranges have been formed by faulting, but the larger streams, i. e., the Columbia and Yakima, were able to cut down their channels as rapidly as the ridges were upraised athwart their channels."^d

The structure of the range is thus described:

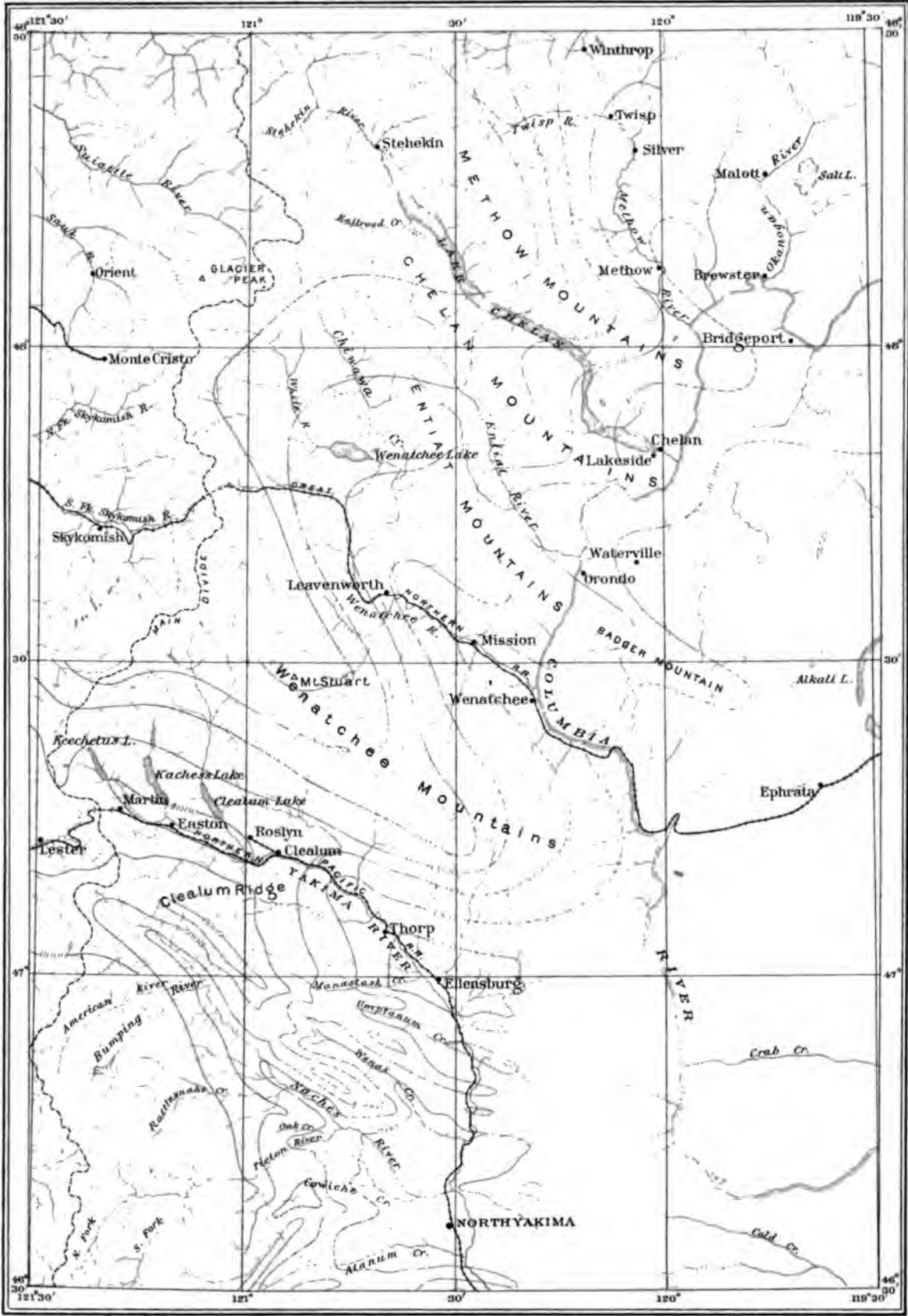
"It seems probable that the Cascades are formed to a large extent of tilted blocks of basalt which were originally horizontal, and belong to the same series as the Columbia [River] lavas farther east, which have been, in comparison, only moderately disturbed. The Cascade Mountains, at least in the State of Washington, do not seem to have been formed mainly by the piling up of erupted material, as has been suggested in explanation of their origin farther south, but are due to the

^a A geological reconnaissance in central Washington. Bull. U. S. Geol. Survey No. 108, pp. 20-25.

^b This has later been termed by Russell the Columbia River lava.

^c Ibid., p. 24.

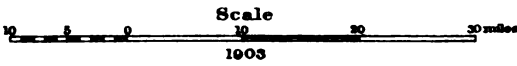
^d Ibid., p. 97.



Drained from topographic maps
of the United States
Geological Survey

Northern half by Bailey Willis
Southern half by George Otis Smith

MAP OF CENTRAL WASHINGTON
CONTOURS ON RESTORED WARPED SURFACE OF THE METHOW (PLIOCENE) PENEPLAIN



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uplifting and tilting of previously consolidated lava sheets, as well as of granite and coal-bearing strata, which occur high up on each flank of the mountain, and even form portions of the main divide. The great volcanoes which appear so prominent along the general trend of the range are secondary to the main mountain building."^a

In a later publication^b Professor Russell describes more fully the Columbia River lava, and states that its maximum thickness in the Snake River region is over 5,000 feet.^c The geologic history of the whole of the Columbia Plains area is sketched.^d In early Tertiary times there were mountains in what is now northern Washington and eastern Idaho, but the central and southern portions of the Cascades were not yet in existence. In the area now including the great plain of the Columbia sedimentation went on in early Tertiary times, clays and sands being deposited, with accumulations of vegetable matter later changed to coal. Upheaval of these sediments "brought these once level sheets of rock above the sea and raised them into a mountain range, the southern Cascade." Erosion followed this upheaval, and later came the eruptions of the basaltic lavas which were spread over thousands of square miles. Succeeding the volcanic outbursts came lacustral sedimentation in broad lakes, probably formed "by the upheaval of the Cascade Mountains." These Miocene sediments are those which Professor Russell earlier called the John Day. Since the draining of the Miocene lakes Snake River has performed an immense task, having carved in the basalt plateau a gorge about 15 miles broad at the top and in places about 4,000 feet deep.

A later paper gives a fuller development of Professor Russell's^e interpretation of the geologic history of the Cascade Range. The geologic formations are more fully described, mention being made of the older metamorphic schists, the igneous rocks, granite, greenstone, and serpentine, the sedimentary rocks of pre-Cretaceous, Cretaceous, and Tertiary age, and the Columbia River lava and volcanic rocks of Glacier Peak. On the subject of the structure of the northern Cascades Professor Russell says: "It will be seen that the structure of the range is highly complex, and is by no means a single great, north-south anticline, or a simple monoclinical block sculptured by erosion."^f Attention is also called to lateral folds and faults on the eastern side of the range in central Washington, and the age of these secondary disturbances is shown to be late Tertiary or post-Tertiary, and apparently contemporaneous "with the latest great upward movement in the Cascade Mountain mass." Again the author notes the antecedent character of the Columbia and Yakima, which cross in narrow gaps these "tilted blocks." The origin of the range

^a A geological reconnaissance in central Washington: Bull. U. S. Geol. Survey No. 108, p. 30.

^b A reconnaissance in southern Washington. Water-Sup. and Irr. Paper No. 4, U. S. Geol. Survey.

^c Ibid., p. 42.

^d Ibid., pp. 88-98.

^e A preliminary paper on the geology of the Cascade Mountains in northern Washington: Twentieth Ann. Rept. U. S. Geol. Survey, pt. 2.

^f Ibid. p. 137.

is thus stated: "The Cascade Mountains, as we know them, seem to have been carved from an upraised peneplain. This plain we term the Cascade peneplain, and the plateau may be conveniently designated the Cascade plateau."^a Russell's hypothesis of a Cascade peneplain rests upon the presence of truncated folds, stream erosion having reduced the whole region nearly to sea level. "During the later portion of the time of base-leveling, the widely spread sheets of Columbia [River] lava were poured out. The date of the period of planation is shown approximately by the fact that folded beds of Eocene age were truncated. The broad peneplain must therefore have reached its greatest degree of perfection in late Tertiary time, probably extending into the Pleistocene."^b It will be noted that the epoch of great basalt eruptions is thus included in the period of reduction to base-level.

In brief, Professor Russell's "conception of the origin of the larger topographic features of the northern Cascades is that the region, having a complex structure, was reduced by erosion to a condition of low relief, and at a later date than the folding of the Tertiary sediments and the outspreading of the Columbia [River] lava was broadly upraised about 7,500 feet in the axial region. The courses of the larger streams were then established and the plateau was deeply dissected."^c The author then describes the extent to which the dissection of the Cascade plateau has proceeded, and mentions in this connection the striking feature that the larger streams of central Washington, of which Yakima River is the best example, have carried the low grade far back toward the axis of the range.^d It is also noted that the courses of the streams are in a marked way independent of the structure of the upraised region.^e

In attempting to determine the position of the upraised peneplain surface, Professor Russell observes that no recognizable flat-topped remnants of the original plateau are to be found in the more elevated portions of the range, but that the sharp-crested ridges and acute peaks may testify to a general diminution in height in the case of the soft rocks, while the harder rocks, such as the granites, more nearly approximate the original elevation of the plateau. Such evidence that the surface of the Cascade plateau has been somewhat lowered by erosion is not thought by Professor Russell to be conclusive.^f

In a later paper,^g Professor Russell goes into a discussion of the character of the plateau which was built up by the Columbia River lava. Taking as a premise the general parallelism of the succession of the lava flows as exposed in canyon walls, he argues that during the period of eruption there were no general movements such as would cause unconformities within the Columbia River series. This lava is

^a A preliminary paper on the geology of the Cascade Mountains in northern Washington: Twentieth Ann. Rept., U. S. Geol. Survey, pt. 2, p. 140.

^b Ibid., p. 144.

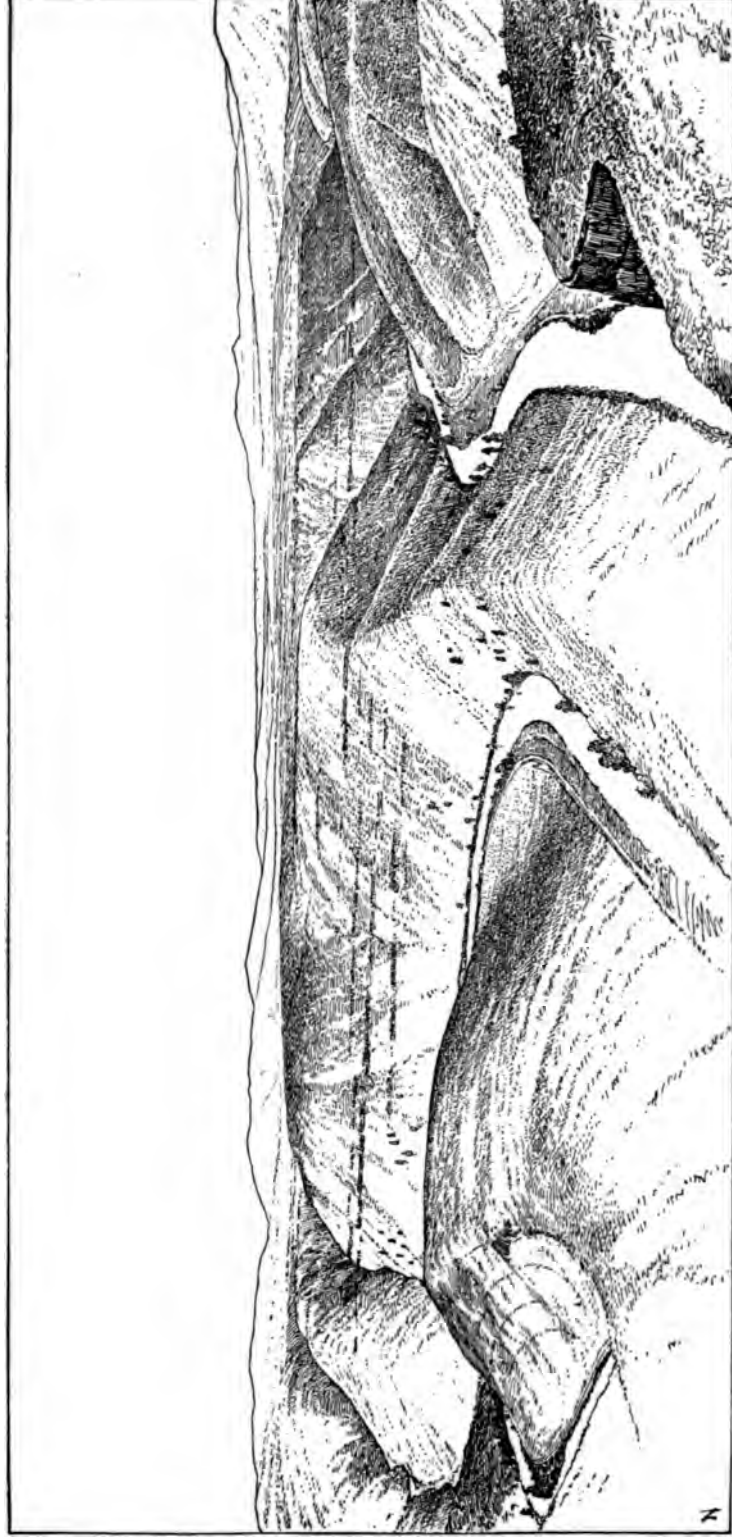
^c Ibid., p. 142.

^d Ibid., p. 145.

^e Ibid., p. 150.

^f Ibid., p. 141.

^g The geology and water resources of Nez Perces County, Idaho: Water-Sup. and Irr. Paper No. 54, U. S. Geol. Survey.



YAKIMA CANYON AT BEAVERTAIL BEND.



believed to have been poured out in a "series of vast inundations over a deeply eroded land surface." Since the series is in places over 4,000 feet thick, if there was no subsidence during the period of eruption the surface of the last flow must have had at least that elevation above the sea. That there were no movements producing a depression during the period of eruption is believed by Professor Russell on the grounds that there are no marine sediments interbedded with the lava sheets; and neither have unconformities been detected in the eastern portion of the area covered by the Columbia River lava. On this account the horizontal surface of the lava plateaus in eastern Washington and Oregon and the adjacent part of Idaho should have an elevation of at least 4,000 feet or more above the sea. On the contrary, the elevation of such plateaus is between 3,000 and 3,300 feet, and this difference of approximately 1,000 feet is supposed by Russell to indicate a general subsidence of the eastern portion of the lava region. In his discussion of the drainage of this area Professor Russell, however, still regards Snake River where it crosses the lava plateau as an antecedent stream.

GEOLOGY.

FORMATIONS.

The two quadrangles which this paper chiefly describes contain rocks of various ages. The geologic section is fairly representative for the whole State, and its discussion is therefore of more than local interest. Pls. III and IV show the geology of characteristic portions of the two quadrangles. The separation of the older and the younger rocks is an obvious one, and would be noted by any close observer. In a general way it may be stated that within this area the oldest rocks lie to the north, in the vicinity of Mount Stuart, and the youngest to the south. To describe this section as a southward-dipping monocline, however, would be misleading, since this would disregard the many marked unconformities which separate the different formations.

In this chapter the rocks will be grouped according to age as pre-Eocene, Eocene, and Miocene and later. The first class includes rocks that are unfossiliferous and plainly more or less altered, with intrusive rocks predominating. Above the base of the Eocene the rocks are fresher in appearance and contain fossils by which their exact age is determined, while the igneous rocks are chiefly surface volcanics. The Miocene rocks are so fresh appearing that in places it is difficult to distinguish them from recent deposits. Thus it will be seen that the grouping adopted is a natural one.

These formations are more fully described in the Ellensburg folio, No. 86, and the Mount Stuart folio, which is in the course of publication.

PRE-EOCENE.

Easton schist.—This is probably the oldest rock to be found in central Washington. It is not shown upon either of the accompanying geologic maps, but occupies a few square miles in the southwestern part of the Mount Stuart quadrangle and extends westward into the Snoqualmie quadrangle. Here it forms in large part the southern wall of the Yakima Valley, and is especially prominent southeast of the town of Easton.

The Easton schist is typically a silver-gray or green rock, composed principally of quartz and micas. The schist is extremely crumpled and is gashed and seamed with veins and stringers of quartz. Associated with this quartz-mica rock are other schists, containing hornblende or epidote, while quartzite is also found. The occurrence of this quartzite in close association with the schists is believed to indicate the sedimentary origin of the schists.

Peshastin formation.—South of the Mount Stuart massif occurs a series of sedimentary rocks that may rank next to the Easton schist in age. These are black slate, with grit or conglomerate, and bands of black chert and lenses of light-gray limestone interbedded with the slate. In places these rocks show metamorphism by the igneous rocks with which they are in contact, and nowhere in the many exposures of this formation have any traces of fossils been discovered.

It seems plausible to assign this sedimentary formation to the Paleozoic, and it is possible that it is of Carboniferous age. This age determination rests simply upon a general resemblance of the formation to the Carboniferous rocks of the Sierra Nevada and of British Columbia. Rocks also strikingly similar to the Peshastin formation are found in the Blue Mountains of Oregon and in the Okanogan Valley in northern Washington.

Hawkins formation.—This is a volcanic series of flow-breccias, tuffs, and amygdaloids. These rocks are dark colored, green, or purple, extremely altered, and everywhere exerting a marked influence upon the topography, rough slopes with ragged crests being characteristic of this formation. While composed largely of secondary minerals, these lavas and tuffs preserve their original textures, and microscopic study shows that the rocks were originally composed of augite and plagioclase, with diabasic texture. The whole series undoubtedly represents surface lava flows with associated tuffs. The Hawkins and Peshastin formations have been intricately mingled by close folding, while subsequent intrusions of igneous rock have also obscured relations.

Igneous rocks.—Surrounding the older rocks just described are great belts of serpentine. This rock is intrusive, and its extent within the Mount Stuart quadrangle is important, since it covers nearly 50 square miles. The serpentine is an altered phase of peridotite, the latter rock being found in its original state at many



- LEGEND**
- SURFICIAL ROCKS**
- PLEISTOCENE**
- Valley alluvium
- SEDIMENTARY ROCKS**
- EOCENE**
- Roslyn formation
(sandstone and shale)
- Swauk formation
(sandstone, shale and conglomerate)
- PRE-EOCENE
(CARBONIFEROUS?)**
- Peshastin formation
(slate and grit with limestone lenses)
- IGNEOUS ROCKS**
- POST-EOCENE**
- Rhyolite
- EOCENE**
- Teanaway basalt
- Gabbro
- PRE-EOCENE**
- Mount Stuart granodiorite
- Diorite porphyry
- Peridotite and serpentine
- Hawkins formation
(breccias, tuffs, and amygdaloids)
- Basalt dikes
- Acid dikes
- METAMORPHIC ROCK**
- Contact schist

GEOLOGIC MAP OF A PORTION OF MOUNT STUART QUADRANGLE

Topography by G.E. Hyde

WASHINGTON
Scale

Geology by George Otis Smith
assisted by G.C. Curtis

1 0 2 MILES
Contour interval 100 feet

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places in the area. No rock can be more varied in color or in physical characters than is this serpentine. It ranges from bright red to light green in color, and forms bold crags with gigantic talus blocks below, or rounded hills covered with fine shingle resembling broken glass.

The serpentine and older rocks in which it is intruded contain gold and copper veins. Locally such veins have been found to be very rich, but the amount of low-grade ore far exceeds these bonanzas.

This serpentine is intrusive in the Peshastin and Hawkins formations, but is itself cut by dikes of light porphyritic rock. These latter are doubtless connected with the great batholith which forms Mount Stuart. The rock of the batholith is a typical granodiorite, often containing quartz, but too basic to be called a granite. It is a gray granular rock, quite granitic in appearance. Generally fresh and unaffected by surficial alteration, its constituent minerals can be seen to be white feldspar, black mica, and hornblende, with a few grains of quartz. The granodiorite is everywhere massive, but is jointed and sheeted, this feature giving rise to the spire and minaret details so characteristic of the crest line of Mount Stuart. Dikes of the granodiorite can be traced extending out into the serpentine, so that it is plainly the youngest of the pre-Eocene rocks.

Eocene.

Swauk formation.—The oldest of the four Eocene formations is the Swauk formation, a series of sandstone, conglomerate, and shale, measuring in places at least 5,000 feet in thickness. The age is definitely determined as early Eocene by the fossil flora, and the basal beds are seen to be separated by a great unconformity from the formations upon which they rest. The conglomerate beds are mostly in the lower part of the section and the basal conglomerates are often peculiar in that the pebbles and boulders are derived almost wholly from the rock upon which the conglomerate rests. Thus, the conglomerate may be composed of granodiorite boulders in an arkose matrix or of serpentine blocks embedded in a sand of the same composition. The sandstone is for the most part arkose in character, although to the east the sediment shows better sorting and is more quartzose. The shale is often quite carbonaceous and rich in fossil leaves.

This formation is of economic importance from the gold veins it contains in the Swauk Basin. Most of the gold, however, is found in placers, but the gravels have all been derived from the Swauk formation and the gold is coarse and has not been carried far from the parent ledge.

Teanaway basalt.—Overlying the Swauk sandstone and separated from it by a slight unconformity is a volcanic formation. The Teanaway basaltic series comprises lava flows and interbedded tuffs. The basalt is black and very compact and makes a

prominent rock. The tuffs are very irregular in their distribution and the thickness of the whole series varies within the area from thousands of feet to a few hundred.

This basalt has been termed by Russell the lowest or first sheet of Columbia River lava, but its importance in the stratigraphy of the region seems to warrant a more definite separation from the Miocene lava to be described later. The most striking feature of the Teanaway basalt is the occurrence of hundreds of dikes which cut through the underlying Swauk formation and connect with this surface flow. The opportunity is afforded for observing almost diagrammatically the evidence that these basalt flows were erupted through many fissures, and for the most part the eruption appeared to be unaccompanied by any disturbance of the underlying rocks.

Roslyn formation.—This sedimentary formation overlies the basalt without any apparent structural break, but also without any evidence of transitional sedimentation of interbedded sands and tuffs. A few pebbles of basalt in the basal beds show that locally there may have been erosion of the lava before the sedimentary beds began to be deposited. The Roslyn formation contains sandstones and shales, resembling the earlier Eocene sediments somewhat. Carbonaceous material becomes more important in the upper portion of the formation, where there are several beds of coal. The Roslyn coal seam is of commercial importance, and excellent steam coal is mined in quantities that give the Roslyn mine the first place among the coal mines of Washington.

Manastash formation.—So far as known this formation is limited to the southwestern part of the Mount Stuart quadrangle and the adjacent portion of the Snoqualmie quadrangle. It is a series of sandstone, shale, and conglomerate beds, containing some seams of carbonaceous material, mostly bone. Fossil plants from the shales determine the age of the formation as Upper Eocene, and it is therefore to be correlated with the Clarno formation of the John Day Basin. Although these beds are somewhat younger than the Roslyn formation, which occurs a few miles to the north, the Manastash rests directly upon the old Easton schist, and this relation is believed to indicate nondeposition of the earlier Eocene sediments in this area.

MIocene AND LATER.

Yakima basalt.—This basalt of Miocene age covers a considerable area in the Mount Stuart quadrangle and the larger part of the Ellensburg quadrangle. It extends to the northeast, east, and south of these quadrangles, and also forms a portion of the higher part of the range west of the Ellensburg quadrangle. The base of this great series of lava flows is exposed at many points in the Mount Stuart quadrangle, and the lavas are here seen to rest unconformably upon the Eocene formations. This unconformity between the Yakima basalt and the Manastash formation fixes the age of the lava as early or middle Miocene. It is, in view of

the age determination, possible for this formation that the name Yakima has been applied to it. In earlier reports on central and southeastern Washington, Professor Russell applied the names Columbia lava and Columbia River lava to this rock. He, however, included not only the Miocene but also the Eocene and possibly the Pliocene basalts, as well as the hypersthene-andesite occurring along Naches River, which will be mentioned later as of Pleistocene age. It became necessary in course of detailed areal mapping to separate these various igneous rocks, and therefore the name Yakima has been applied to this formation, which includes only the basalt flows and interbedded pyroclastics which are of Miocene age and thus constitute a series that can be taken as a unit since it represents the products of a volcanic activity uninterrupted by any other important geological process. The Yakima basalt is a normal feldspar basalt containing the usual constituents, plagioclase, augite, and olivine. It is commonly a glassy lava, and in some localities large masses of pure basalt glass can be found. The rock is always dull in color and no crystals can be distinguished except by means of the magnifying glass. In a few localities, notably Bald Mountain, in the Ellensburg quadrangle, the series includes large quantities of fragmental material, the yellowish tuffs including irregular blocks of jet-black glass, some of which undoubtedly represent bombs ejected from the center of eruption. Along Yakima River the tuff beds and scoriaceous lavas are less common than the compact lava.

The number of lava flows in this series varies widely in different parts of the area. At no point is the whole series exposed. The sections shown in Yakima Canyon, where over 2,000 feet of basalt are exposed with neither the top nor base of the series visible, indicate that the actual thickness of the Yakima basalt is probably to be measured in thousands of feet, and 5,000 feet is undoubtedly a conservative estimate. The columnar structure is the most noticeable feature of the basalt where it is exposed in the canyon walls.

In a portion of the Ellensburg quadrangle slightly later flows of basalt occur interbedded with the sandstone which overlies the Yakima basalt. These have been included in the Wenas basalt, which is a formation of only local importance. Similar sheets of basalt are doubtless to be found in other portions of the great area covered with Miocene basalt.

Ellensburg formation.—The only formation in central Washington which is known definitely to be of Miocene age is the Ellensburg sandstone. Collections of fossil leaves made by Professor Russell in 1892 near Ellensburg and by myself in 1900 in Kelly Hollow have afforded material for the determination of the age of the formation, which Dr. F. H. Knowlton fixes as late Miocene. This determination correlates the Ellensburg formation with the Mascall formation of the John Day

Basin in Oregon. The Ellensburg formation also resembles the Mascall in its composition. Both formations are composed largely of volcanic sediments, the sandstones and shales consisting of the finely comminuted andesitic material and the conglomerates containing pebbles and boulders of andesitic lavas. In both cases the lava from which the sedimentary material was derived is not exposed within the area where the sedimentary rocks have been studied. This volcanic series doubtless occurs in the higher parts of the range to the west.

Along Naches River over 1,500 feet of the Ellensburg formation are exposed, and the formation is characterized by coarseness of material, together with its prevailing andesitic composition, and also the common occurrence of stream bedding. A section of this formation exposed at White Bluffs, on Columbia River, is described by Professor Russell^a as consisting of "fine, thin-bedded sand and clay, with layers of pure white volcanic dust." The field evidence, therefore, indicates that in the Yakima region the Ellensburg formation is to be considered as of fluvial origin, while farther east along the Columbia the formation is plainly of truly lacustrine type. The cross stratification or stream bedding shows that the material was distributed by eastward-flowing streams. These stream sediments vary considerably in thickness within short distances, as would be expected, and at some points the stratification is so confused that individual beds can not be traced far. At localities, both in the Ellensburg and the Mount Stuart quadrangles, boulders of andesite measuring at least 5 feet in diameter have been found in the Ellensburg conglomerate, proving that powerful currents must have transported the material.

Later lavas.—The lava from which the Ellensburg sediments were derived was light-colored and contained hornblende as an original constituent. Later lavas of a somewhat different type occur in central Washington. The most prominent of these is the hypersthene-andesite which forms a long lava stream extending from the Tieton Basin west of the Ellensburg quadrangle down Tieton Canyon and along the Naches Valley nearly to Yakima River. This lava was erupted after the basalt and Ellensburg rocks had been uplifted to their present positions, and at a time when the topography was essentially the same that it is to-day. The lava is, therefore, of Pleistocene age, and where not exposed to erosion by Tieton River the lava stream preserves the form which it took when it came to rest. The surface of the andesite plateau between Naches River and Cowiche Creek is exceedingly hummocky and full of undrained basins, while its margins, which have been affected by stream erosion, show the radiating columns into which the lava parted at the time of its consolidation.

Somewhat different lavas occur on the middle fork of Teanaway River, where rhyolitic rock is seen to rest upon the eroded surface of the older rocks. The age of

^a Bull. U. S. Geol. Survey No. 108, p. 97.



this lava is somewhat problematical, but evidently it is considerably younger than the Eocene rocks with which it is in contact.

Pleistocene deposits.—In the heart of the Cascade Range the valleys of the larger streams exhibit abundant evidence of glaciation. Within the area here described glacial deposits are not found except in the vicinity of Mount Stuart, which was a local center of glaciation. The valleys of Yakima River and most of its tributaries within the Mount Stuart quadrangle are gravel filled. These valley gravels attain great prominence in the upper valley of the Yakima and plainly once filled it to a considerable height, and diamond-drill records indicate that the river has not yet reached its former floor. The gravel terraces constitute a noticeable feature here, but are much less important than similar terraces upon the Columbia, which will be mentioned by Mr. Willis. In the Swauk drainage basin these terrace gravels are auriferous and have been mined for many years.

STRUCTURE.

Certain of the structural features have been mentioned in the foregoing description of the formations. A more complete statement of what has been learned concerning the geologic structure of the region will be given here, since the area affords excellent opportunities for studying the course of events in the dynamics of the mountain building. The two quadrangles present two types of structure, but both are representative for the Cascade Range.

MOUNT STUART QUADRANGLE.

The oldest rocks were intricately folded and faulted before the intrusion of the peridotite, and this accounts for the greater metamorphism which characterizes the schists, slates, and greenstones. The intrusive peridotite, now largely altered to serpentine, appears to have suffered similar dynamic action, but its record of deformation is doubtless much less significant. The rock is commonly crushed and sheared, but this condition indicates rather a lack of resistance on the part of the soft serpentine than intensity of the deformation forces. In fact, in large measure, the development of the zones of sheared material within the serpentine mass may have been due to the expansion incident upon the serpentinization of the peridotite. This alteration, with the resulting crushing, is known to be pre-Eocene in age, since the boulders with slickensided surfaces, so characteristic of the zones of shearing, are found in the basal conglomerates of the Swauk formation.

The jointing of the granodiorite is its only structural feature, since nowhere is the rock schistose. This batholithic intrusion doubtless played a considerable part in the pre-Eocene structure of the region, but no deformation of the older rocks can be definitely traced to this igneous rock, unless the hydrothermal alteration of the peridotite may be attributed to the intrusive granodiorite. The presence of small

dikes extending from the latter rock into the adjacent serpentine shows the absence of any later differential uplift of the massive granodiorite.

The earlier Eocene rocks appear to have been subjected to deformation soon after their deposition. The folds are open, with steep inclination of the strata exceptional. Within the area south of the Mount Stuart massif, a half dozen folds may be traced, the anticlines and synclines having axes which trend northwest-southeast. This structure, in part at least, antedates the eruption of the Teanaway basalt, since that rock lies upon the somewhat eroded folds of the Swauk sandstone. Later, however, these folds may have been further developed.

The manner in which the rocks of the Swauk formation nearly encircle the Mount Stuart massif suggests that this forms the center of a great dome-shaped uplift, with the Tertiary formations dipping outward. The areal distribution favors this simple explanation of the structure, but detailed study of the various formations makes it plain that a careful distinction must be made between the different movements that have contributed to the sum total of deformation. The attitude of the Mount Stuart massif at the commencement of the Eocene sedimentation can not be determined, except that this mass of granodiorite is known to have furnished the bulk of the detritus for the Swauk sediments. These strata on the south side of Mount Stuart then became folded, as has just been described, and uplifted so as to suffer erosion. If the structure developed at this time may be determined by the distribution of the basaltic lavas which flowed out in the succeeding epoch, it appears that there was not only an elevation in the vicinity of Mount Stuart, but also on the eastern and the southern part of the Mount Stuart quadrangle. The rise of the Wenatchee Mountains dome does not appear to have been so prominent a feature at this time as the development of an east-west trough in the central portion of the Mount Stuart quadrangle. In this depression, the molten lavas consolidated and the tuffs were laid down, and later the Roslyn sediments were deposited, the latter formation possibly covering in its original extent an even more limited area than did the Teanaway basalt.

Clealum Ridge, which bounds the Yakima Valley on the south, has certain topographic characters suggestive of a fault scarp. The structural relations show, however, that this marks the southern side of the syncline developed in the Teanaway and Roslyn formations, and its topographic prominence is due to the older rocks which rise here above the Eocene strata to the north. In middle Miocene time this ridge had much the same relative prominence, as is shown by the way the Yakima basalt abuts against and caps it, while filling the neighboring depressions. This post-Roslyn folding may have been coincident with the deformation of the Manastash strata, and thus belongs to the close of the Eocene period.

ELLENSBURG QUADRANGLE.

The post-Miocene deformation can be studied best in this quadrangle, where only Miocene formations are present. Yet, while pre-Miocene structures can thus be avoided here, it is necessary to distinguish between the flexing or moderate folding to which the Yakima basalt and the Ellensburg sediments were subjected soon after the deposition of the latter, from a later movement which affected the same rocks. These later structural features are so closely connected with the topographical features of the area that their discussion will be given under the heading "Physiography."

In the present connection, however, it may be well to call attention to a certain structural feature of the Yakima basalt. This is the almost universal occurrence of parting or jointing in the rock, by which the lava sheets are divided into the typical basaltic columns. This contraction parting took place normal to the surface of the lava flow, so that where the basalt has its original position undisturbed the joints are vertical. The presence of innumerable joints of this character, of course, would greatly facilitate the flexing of the basalt sheets, and, since the Yakima basalt is the more important formation in the Yakima region, this feature must not be disregarded in any consideration of the deformation of this area. Furthermore, this may serve to explain why the post-Miocene deformation, which will later be described as taking place at the surface, was not of the nature of faulting as that term is generally accepted. The structural ridges are not "tilted blocks" but anticlines.^a

HISTORY.

The geology of central Washington may be best summarized by a brief résumé of the geologic history of the area.

The oldest rocks, probably of Paleozoic age, furnish a record of sedimentation and volcanism, but this record has been greatly obscured by the altered condition of these rocks. This metamorphism in turn tells of the orogenic movements to which the rocks have been subjected and of the action of intrusive magmas.

The great intrusions of peridotite and granodiorite probably belong to the Mesozoic, and were events of the first importance in the history of this portion of the Cascade Range. The period of erosion subsequent to these intrusions was of sufficient length to allow these deep-seated bodies to be uncovered and deeply dissected.

From these eroded older rocks was derived the material for the Eocene sediments, and the process of sedimentation appears to have been a rapid one within this area, since several thousand feet of granitic sands and other sediments were deposited in early Eocene time, before uplift again inaugurated erosive activity.

^a This absence of faults in this area has been discussed in a recent paper by the author—Anticlinal mountain ridges in central Washington. Jour Geol. Vol XI 1903 pp 166-177.

Then began the first basaltic eruptions, the forerunners of the greater volcanism of the Miocene. This volcanic activity was succeeded by the quieter processes of sedimentation, by which the Roslyn sandstone was deposited in middle Eocene time. Somewhat later, in an adjacent area, the deposition of the Manastash sediments took place, and the Eocene period closed with the uplift and folding of all of these Eocene formations.

Erosion continued well into the Miocene within this area, but ceased with the beginning of the great eruption of basalt, the many flows of which covered the greater part of central Washington like a molten sea. Immediately succeeding this epoch of volcanism came the deposition of the Ellensburg formation, thick deposits of stream sands and gravels, brought down from a volcanic area to the west.

Mountain-building movements followed this sedimentation of the later Miocene, and again erosion began to cut away what had been uplifted. The Pliocene and post-Pliocene history is recorded in the topography, and will therefore be discussed in the following chapter.

Even this brief summary is sufficient to indicate how eventful has been the geologic history. Especially in Tertiary time is it true that this region has been one with relatively many changes. The many well-marked unconformities testify to the frequency of these geologic revolutions, so that geologic formations are easily separated upon the basis of structural breaks, whereas in other provinces such subdivision would need to be based wholly upon paleontologic evidence.

PHYSIOGRAPHY.

TOPOGRAPHIC DESCRIPTIONS.

MOUNT STUART REGION.

Mount Stuart, 9,470 feet high, lies 15 miles east of the main crest of the Cascade Range, and forms the culminating peak of the Wenatchee Mountains. These mountains constitute a secondary range transverse to the general trend of the Cascades, but are characterized by the same rugged topography as the main range. The mountain crests are deeply carved into spires and crags, while precipitous slopes descend into glacial amphitheaters where remnants of glaciers still persist. South of Mount Stuart, and extending almost to Yakima River, there is a belt of hardly less rugged topography. Here the valleys are deep and canyon-like and the divides are sharp and narrow. Dissection has apparently reached the extreme limit, and the topography may be termed mature. The gradient of the streams is largely determined by rock hardness, and many of the minor topographic features, such as peaks and gaps in the crest lines of ridges, are also referable to varying resistance of the different rocks. Pl. III is a map of a portion of the Mount Stuart quadrangle, showing the topography typical of this area.

The southern part of the Mount Stuart quadrangle includes an area quite distinct in its topographic features from that described above. Here there is a transition into the type of topography characteristics of the Yakima region. While the streams may have canyons similar to those farther north, they are farther apart. The divides are broad and comparatively level topped. The valley of the Upper Yakima forms the dividing line between the two areas, and the surface geology is also quite different on the two sides of this valley, in the vicinity of Clealum. On the south the prominent escarpment of the Yakima basalt overlooks the river and on the north are the lower ridges of Eocene sandstone. However, the differences in topography are not wholly due to the geology, as will be shown in a later section of this paper.

YAKIMA REGION.

That part of Yakima County which lies adjacent to the course of the river of the same name possesses a topography that is unique. Its origin will be fully discussed in the following pages, so that only a brief description is necessary here. In its general features this topography is very simple. Long canoe-shaped valleys, with intervening ridges, form a quite constant succession with the general trend transverse to the course of Yakima River. Some of the valley floors reach the river level while others lie several hundred feet above the bottom of the river canyon. The ridges rise from 1,000 to 3,000 feet above the valleys, with fairly gentle slopes and even crests, except where interrupted by the deep water gaps of the river. The relation of these ridges and valleys to the river may be seen in the sketch map of Yakima Canyon (Pl. VI); and the topography of a typical portion of the region is given with more detail in Pl. V. Pl. II shows very well the character of Yakima Canyon where it cuts through Manastash Ridge.

This description of the topography would be incomplete without mention of the landslides that are common in central Washington, a topographic form fully described by Prof. I. C. Russell in several papers. The active canyon cutting and favoring geologic structure has caused this area to afford wonderful examples of landslide topography. One of the best of these is on the southern slope of Cleman Mountain, and is well represented on the physiographic map (Pl. V). These landslides vary in size from some to be measured by cubic miles of displaced rock to others involving less than an acre of surface. In age this range is scarcely less striking, certain landslides antedating the high terrace gravels deposited when glaciers occupied the Upper Yakima Valley, while other slides are of so recent origin that vegetation has not yet gained a foothold.

CASCADE LOWLAND.^a

IDENTIFICATION.

As was noted in the discussion of the literature, Professor Russell finds in the plateau-like surface of the Cascade Mountains evidence of previous reduction of the region "to a plain, or an approximately plain, condition nearly at sea level." This was the "Cascade peneplain," the subsequent elevation of which resulted in the "Cascade plateau." In view, however, of the complete dissection of this plateau into a complex of sharp ridges and peaks, as described by Russell, it is evident that both plateau and peneplain are somewhat hypothetical. A general uniformity of altitude of the ridges and peaks of the central portion of the Cascades may be made out in certain districts, but so frequently are other peaks seen which rise above this level that this class of evidence taken alone is far from conclusive. Indeed, this is best appreciated by those who have been most earnest in their search for traces of the old peneplain. Furthermore, the date of the supposed planation has not hitherto been determined even approximately.

The identification of possible remnants of the old lowland, if such a lowland existed, becomes most essential to the investigation of the later history of the Cascade region. By reason of the aridity of its climate and consequent slight erosion the conditions in the area along the lower course of Yakima River are most favorable for the preservation of land forms. Erosive activity is mostly confined to the larger streams which head in areas to the north and west where the precipitation is greater. Under such conditions it appears quite possible for deformation to outstrip erosion, with the result that the relation between structure and topography becomes at once both close and obvious.

At first glance, the topography of this Yakima region is seen to be dependent upon structure. The ridges are anticlinal and the valleys synclinal. This relation necessarily involves a more or less perfect parallelism between the surface and the rock structure. The parallelism may or may not be easily observed, but the determination of the degree of this conformity between structure and surface becomes of the greatest importance.

The first hypothesis to suggest itself in the course of the field work in the northern part of the area here discussed was that the anticlinal and monoclinal ridges bounding the extensive Kittitas Valley were in a great measure pre-Ellensburg. This valley with its floor of Ellensburg sandstone, horizontal or only gently inclined upward at the borders, has the general features of a structural basin in which lacustrine sediments have been deposited. Such a view would involve an unconformity

^a Cascade is here used purely in a geographic sense. To express the period of development of this lowland, Mr. Willis's term "Methow" would be more exact, and its use becomes necessary in his more detailed discussion of the successive stages in the history of the Cascade Range.

between the Miocene lava and the succeeding sediments, and the Ellensburg formation would be found to occur only in the synclinal basins where it had been deposited. Further study of the area, however, showed that the distribution of the Ellensburg formation is too general to permit of its being considered a local deposit of the character suggested.

The second explanation to be tested in the field was that the soft sandstones had been eroded from the crests and higher slopes of the anticlinal ridges, the Ellensburg thus being left only in the lower parts of the synclinal valleys. This apparently was the opinion held by Professor Russell in his reconnaissance of the Yakima region. On this supposition, it was not pre-Ellensburg but post-Ellensburg movement that uplifted the anticlinal ridges of the area. Subsequent to the warping of the surface of the Miocene sediments, erosion removed the softer beds from the ridges, which determined the general distribution of the Miocene rocks as now observed, the upfolded basalt forming the ridges, and the Ellensburg sandstone occurring in the valleys between. In this way there was a perfect conformity between surface and structure, although with a subsequent destruction of this original surface, except in the floors of some of the basins or valleys, where the whole thickness of the sedimentary formation may have been preserved. The level tops of the ridges, therefore, while not preserving the original surface, would be parallel to it and in a way represent it, since the sheets of resistant basalt parallel to the original surface have determined the present surface.

This second hypothesis also had to be abandoned because field evidence did not support it. The essential feature of conformity between surface and structure was found to be wanting, so that it became evident that the true explanation is less simple. Where the even surface is best preserved, on the level crests of the ridges and on the long, gentle, and smooth slopes along the flanks of the same ridges, it is apparent that this surface does not parallel the underlying rock structure. The dip of the rock and the inclination of the slope agree in direction but differ in amount. The rock dip commonly exceeds the slope, and higher beds occur in the valley than can be found on the ridges, and while such valleys may be unsymmetrical with regard to the slopes on either side, the rock folds are even less symmetrical.

Tracing the rock slopes of the valley sides upward until the even crests of the ridges are reached, lower sheets of the basalt are successively crossed, until it is evident that the crests of the anticlines have suffered considerable erosion, so that the highest beds are found in the synclinal valleys and the lowest on the crests of the anticlinal ridges. The result has been more than the erosion of the softer sandstone strata from the ridges and their preservation in the neighboring valleys. The surface is thus an erosion product and cuts across both the folded Yakima basalt and Ellensburg sandstone.

This beveling of rocks as widely different in their resistance to erosion as the hard, compact basalt which withstands the attacks of stream corrasion and the soft friable sandstone easily eroded even by the desert winds is especially noteworthy in connection with the present discussion. The absence of any scarp or other topographic form expressive of differential resistance of the two rocks indicates a long continuance of the erosive activities producing this surface. Such perfection of planation could not be expected much short of reduction to a baselevel, so that the natural deduction from these observed facts is the former presence of an essentially level lowland over the area. Therefore, the third hypothesis was adopted in the field, namely, the ridges and valleys of the Yakima region represent a warped lowland surface. The relation of this surface to the rock structure is not a simple one. The reduction of the area of previously folded rocks to a lowland caused any perfect conformity between the surface and the structure to be very exceptional, while on the other hand, the general or approximate parallelism between the two as observed at many points becomes explicable from the fact that the warping of the lowland surface was in the main along lines coincident with the axes of prelowland folding. This double deformation resulted in steeper dips for the rock strata, which were subjected to both movements, and more gentle inclination of surface slopes which have been affected only by the later warping.

DEVELOPMENT.

The extent of this Cascade lowland and the degree to which it was developed may next be considered. In the Yakima region exceptional conditions favor its preservation, and the recognition of this physiographic feature is easy. Detailed mapping reveals the fact that the Cascade lowland was, in this area at least, a comparatively perfect one. Remnants of the old lowland now uplifted on the flanks of the anticlinal ridges are seen to have a remarkably uniform surface. On the sketch map of a portion of the Ellensburg quadrangle (Pl. V) are indicated the portions of the old lowland surface that have escaped destruction by later erosion. In the field the evidence appears much less fragmentary than on the map. The narrow gulches that score the sides of the ridges are unsuspected when one looks along the slope. What is seen is a gently inclined featureless surface extending from the even crest of the ridge to the valley floor below, often without a perceptible break. This surface is commonly covered with basaltic debris, usually quite coarse, which has been derived from the basalt exposed in the immediate vicinity. On some very gentle slopes a thick deposit of fine silt is found. Whether or not this may represent a lowland deposit can not be definitely stated, but its present distribution is in part due to wind action.

On this planation surface it is often impossible to trace the contact between the

LEGEND



Remnants of lowland surface



Landslide areas



PHYSIOGRAPHIC SKETCH MAP OF A PORTION OF THE ELLENSBURG QUADRANGLE, WASHINGTON

Topography by A. E. Murlin

Scale

Physiography by George Otis Smith



two formations. The accompanying illustration (fig. 1) shows such a case, and is drawn from a photograph of the spur east of Kelly Hollow on the southern slope of Umptanum Ridge. This may be considered the type locality for the recognition of the lowland surface. The plateau is several hundred yards in width and over a mile in length, and preserves its even surface to the very brink of the steep-sided gulches that bound it on the east and west. The surface is thickly strewn with angular boulders of basalt, and there is not the slightest indication of the contact between the Yakima basalt and the overlying Ellensburg sandstone. On either side, however, on the walls of the gulches the position of this contact can be accurately fixed and its dip seen to be 20° . Here, then, the planation was complete and the resultant lowland surface is perfectly preserved.

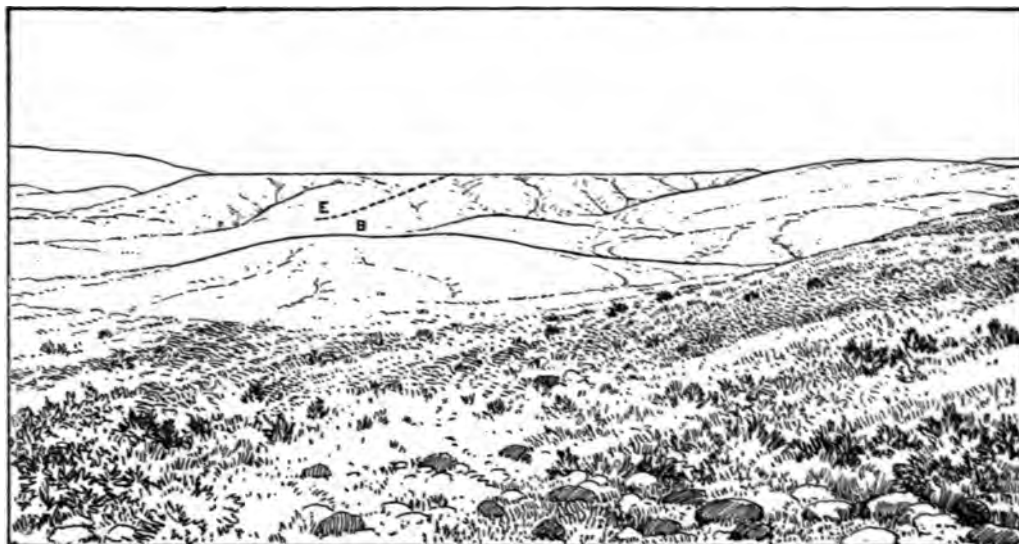


FIG. 1.—Contact of Ellensburg sandstone and Yakima basalt—E, Ellensburg; B, Basalt.

The profile of the deformed lowland, with the relation of this surface to the rock structure, is well shown in the section on Pl. VI. This section extends from Ellensburg to the vicinity of North Yakima, and while in a general way it is parallel to the accompanying map, it was made to follow as far as possible the unmodified spurs between the gulches that have been cut into the slopes. It represents, therefore, as well as a true section can, the lowland surface now warped to form the ridges and valleys of this area.

On the slopes of Manastash Ridge, Umptanum Ridge, Cleman Mountain, Cowiche Mountain, Selah Ridge, and Atanum or Yakima Ridge remnants of the Cascade lowland can be detected. Farther north, in the Kittitas Valley, the old surface may be recognized on the slopes of Table Mountain and of Lookout Peak, where the inclination of the surface is seen to be less than the rock dip, in the sloping surface of

the even-topped terrace of Ellensburg sandstone along Yakima River, and in the flat-topped mesa of similar material near the Normal School Building in Ellensburg.

The identification of the old lowland surface becomes more difficult outside the area here described. Eastward, undoubtedly it can be traced to the plain of the Columbia, and to the northeast the even surface of Table Mountain appears to be continued in the even-crested but lower ridges just south of the mouth of Wenatchee River. Table Mountain thus serves to connect physiographically the Yakima region with the area described by Willis in the second part of this paper. North of Lookout Mountain, in the Mount Stuart quadrangle, as may have been inferred from the description of the topography, there are no traces of a peneplain surface. In the western portion of the Ellensburg quadrangle, where the ridges mentioned above unite to form a broad plateau, the distinction can not be made with certainty between the old surface and a possible later erosion feature, which may be determined by the gentle monoclinal structure of the basalt. Especially is this true on account of the absence of the Ellensburg sandstone and the consequent lack of the best criterion for the recognition of the old lowland surface.

The evidence of the reduction of a large area of folded Tertiary rocks to form the Cascade lowland appears conclusive. The date of the development of this lowland is fairly well determined, since folds involving late Miocene strata are truncated, while on the other hand the subsequent history of a large part of the region has been so eventful that the production of the lowland surface could not reasonably have been later than Pliocene. Previous to this Pliocene reduction, erosion does not appear to have ever produced anything like a peneplain in the northern Cascades, as far as its history has been determined. In view of the eventful character of the whole of the Tertiary, it is plain that the period of reduction to base-level can not be considered as including any large part of Tertiary time, as has been suggested by Russell. Uplifts or subsidences of the extent that are known to have occurred during Eocene and Miocene time in this area must be considered as inaugurating new topographic cycles. Furthermore, the land surface that was flooded by the basalt flows at the beginning of the Miocene possessed considerable relief. This pre-Miocene topography has been preserved in a large measure from later erosion by the basalt, and where the capping is partially eroded away and stream canyons are cut down into the underlying formations the contact shows very conclusively the character of the old surface. Such a locality is the valley of Taneum Creek, where it is at once seen that the prebasalt surface was such as to deserve to be termed rugged topography. It seems necessary, therefore, to restrict the period of the development of the Cascade lowland to the Pliocene. ^a

^a It is of interest to note that in the John Day Basin, Merriam finds evidence of the erosion of the upturned Miocene formations early in Pliocene time: Bull. Dept. Geol. Univ. California, Vol. II, No. 9, p. 311.

CASCADE PLATEAU.

CHARACTER OF THE UPLIFT.

Russell's term, "Cascade plateau," is used in this paper as a convenient designation for the uplifted lowland surface. The term is of value as expressive of the change in attitude and as descriptive of the mass from which the Cascade Range has been carved. It is not, however, to be inferred that a broad, unmodified table-land once existed where now there are rugged peaks and deep canyons. The uplift was not catastrophic but slow and gradual, and further knowledge of its character may be gained from the study of the Yakima region.

Here, as has been noted in the previous section, the uplift was effected with pronounced deformation along well-defined axes, producing parallel ridges. This evidence in the region where the upraised surface has been so preserved that definite conclusions are possible suggests that the uplift of the Cascade Mountains was not necessarily of a broad and general character, producing a dome with gentle slopes extending over thousands of square miles, but that the uplift was effected with similar local warping in other parts of the Cascades.

This may serve to explain the lack of uniformity in elevation of some of the higher peaks. Such cases are cited by Russell,^a and he suggests four hypotheses to explain the greater prominence of the granite peaks, of which Mount Stuart is a type. The postpenepine elevation of such masses is rejected on the ground that the structure antedates the period of reduction to base-level. Another hypothesis is that these high peaks represent monadnocks on the old lowland, and another that the higher peaks, being composed of the more resistant granitic rocks, more nearly preserve the original general surface level of the Cascade plateau, which was about 10,000 feet above sea level, while the peaks of softer rocks have suffered a general diminution in height. A fourth hypothesis "calls for local upheavals since the Cascade penepine was raised into a plateau and subsequent to the initiation of the present master drainage lines,"^b an upward movement which is thought possibly to be still in progress. This last hypothesis appears to Russell to best explain the observed facts, and a modification of this may be here suggested in light of the later observations in the Yakima region.

The uplift of the Cascade lowland to form the Cascade plateau on the present supposition was not a simple, broad, flat-topped, anticlinal uplift, but a deformation of more complex character. The Wenatchee uplift was not necessarily a local uplift subsequent to the main Cascade uplift, but rather a part of that uplift and contemporaneous with the localized deformation in the Yakima region. The Wenatchee Mountains are thus comparable to Manashtash and Umptanum ridges to the south, and may, indeed, form the higher part of a somewhat broader uplift,

^aTwentieth Ann. Rept U. S. Geol. Survey, pt. 2, pp. 139-142.

^bIbid., p. 141.

of which the Table Mountain-Lookout Peak ridge, 20 miles south of Mount Stuart, forms the lower flank. On the Wenatchee Mountains apparently no remnant of the old lowland surface remains, although such a surface is suggested by the level platform from which the upper 1,500 feet of Mount Stuart rises as a monadnock, but on Lookout Peak and Table Mountain such a surface can be detected extending down into the Kittitas Valley, as noted above. It must be kept in mind, however, that such an uplift in no sense explains the rock structure, which greatly antedates this surface deformation, but, like the cases cited in the Yakima region, the later uplift was apparently along an older structural axis, and it is only by detailed study of the basal contacts of the different Tertiary formations that the distinction can be made between Eocene deformation and the deformation which followed the post-Miocene reduction to a lowland.

VARYING DEGREE OF DISSECTION.

In the brief description of the topography of the Mount Stuart and Yakima regions the difference in type was pointed out. The variation in degree of dissection is at once apparent. This is in no sense due to differences in the formations eroded, but has its origin in climatic conditions. On the eastern flank of the range the precipitation is scanty and erosive processes correspondingly weak. Only the larger streams that head outside the arid belt accomplish much, so that deformation has been able to quite outstrip erosion, with the result that the warped lowland surface is preserved. On the higher slopes, especially nearer the crest of the range, the precipitation is greater, and active erosion has resulted in mature topography.

It is on account of this deep dissection that there is little remaining to more than suggest the Cascade plateau over large areas in the Cascade Mountains. Whether or not the acute peaks even approximate the old surface can not be determined, but it seems probable that in the higher portions of the range there has been a general diminution of height.

The cause for variation in degree of dissection other than that of a climatic nature is the length of the period during which erosion has been uninterrupted by crustal movement. In one area the topographic cycle may be continued from youth to old age, while in another region not far distant, in the same time, one cycle may be terminated and another inaugurated simply by a local uplift. The physiographic stages enumerated by Willis in his paper have not been differentiated in the foregoing description of the central Washington area. It is doubted, moreover, if such distinctions can be made generally throughout this area, by reason of its physiographic development differing from that of the region described in the following paper. This difference appears possible, and indeed probable, since in the

case of gaps cut by Yakima River in ridges only a few miles apart the record in one case is shown to be that of an uninterrupted uplift of the ridge, while the compound form of the other gap shows a halt in the uplift sufficient for widening the canyon in its earlier portion.

A few points of connection between the two regions may be noted, however. The greater part of the Mount Stuart and Ellensburg quadrangles lies outside the limit of glaciation, and therefore direct reference of the date of topographic features to a glacial episode becomes difficult. The period of development of the Cascade lowland as described for the Yakima region of course corresponds to the Methow stage of Willis. The Entiat stage is poorly represented in the Mount Stuart quadrangle, and the only traces of topography antedating the present are found in the old valley of Camas Land and in several small areas now capped by rhyolitic lava, the pre-lava surface plainly possessing only moderate relief. Elsewhere in the northern half of this quadrangle dissection appears to have proceeded so far as to destroy all evidences of an earlier stage, while in the Yakima region these later stages have not been separated, the uplifted Methow topography having suffered extremely little modification. Since the physiographic development is the result of the interplay of earth forces and atmospheric agencies, it is evident both must remain the same throughout a region to result in the same succession of physiographic stages. Climatic differences appear to account for much of the topographic diversity, but the structural history is no less important. It would seem futile, therefore, to expect uniformity in the physiographic record over wide areas in a province like the northern Cascades if the writer is correct in his belief that the uplift of the range has been complex rather than simple. However, it is no less evident that the more complete record that can be deciphered for the one area is of material value in the understanding of the other area.

There is good reason to expect confirmation of the views here expressed in the course of future work. Already the writer has detected remnants of the uplifted lowland surface in higher portions of the Cascades. The Cascade plateau was also found to be exceptionally well represented immediately north of Mount Baker, near the international boundary. Here there is not only a marked uniformity in the elevation of the ridges, but their crests are broad and even. Such topographic characters belong to an older topography, and it is believed therefore that these features in reality mark the preservation of the lowland surface now uplifted to form the plateau with an altitude of over 5,000 feet. This plateau is incised by the deep canyons of Nooksak River and its tributaries, while upon it rests the volcanic cone of Baker. West of this region, toward the crest of the Cascades, the plateau character is lost and the more complete dissection makes the topography one characterized by the most acute peaks and rugged mountain masses. In this higher portion of the

uplift the attack by erosive agencies has plainly been much more severe, and erosion has outbalanced deformation with the resulting destruction of the plateau type of surface.

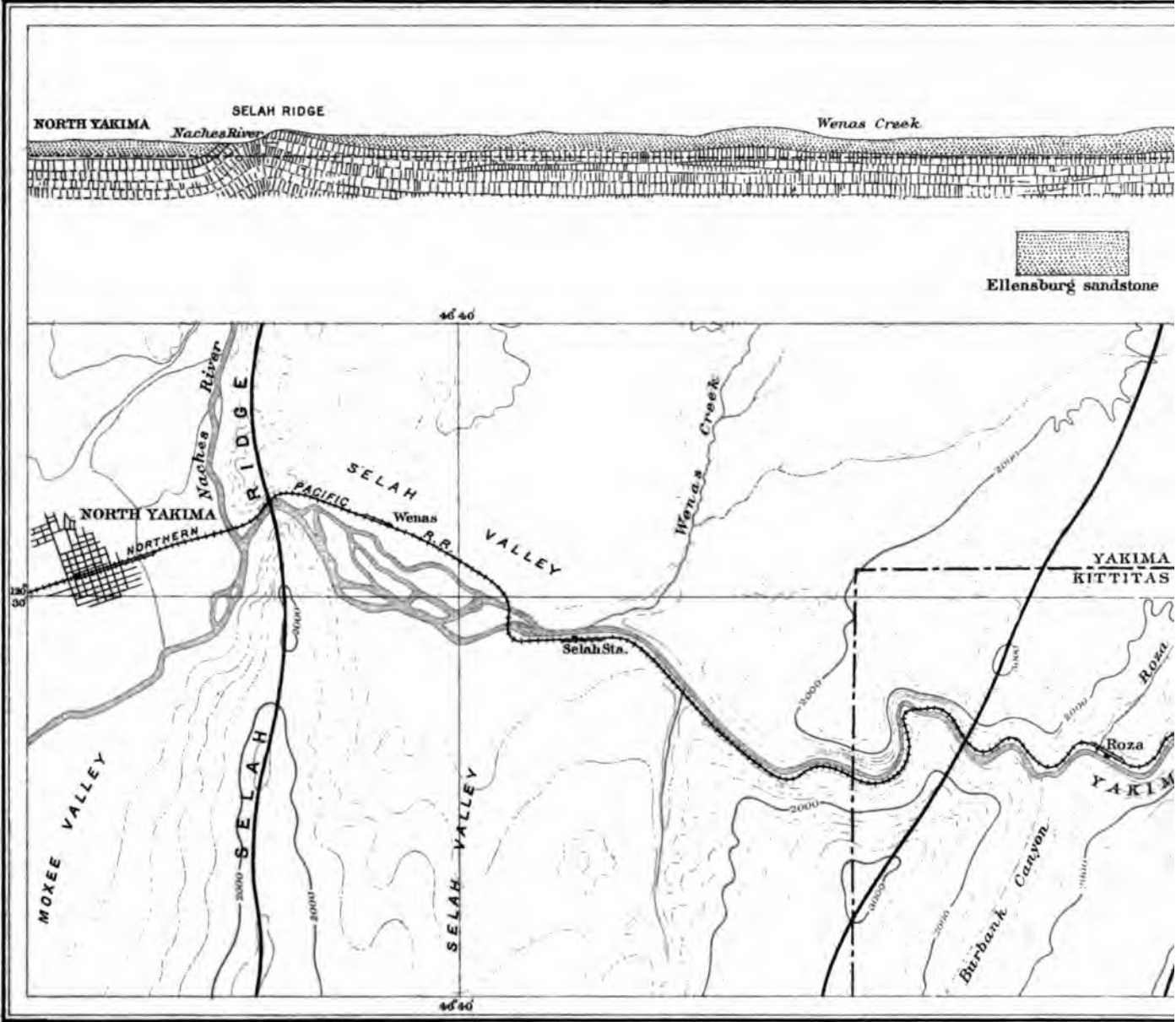
RIVER HISTORY.

In the higher parts of the Cascade Mountains it will probably be found that the only line of evidence bearing upon these physiographic problems is that furnished by the streams. The antecedent character of such streams as the Icicle, which cuts across the granite mass of the Wenatchee Mountains, has been recognized by Russell, and furnishes additional proof of the existence of the Cascade lowland. In considering the history of such streams and their relations to the rock formation across which they have cut their canyons it is most important that a sharp distinction be made between the rock structure and the surface warping. The former is the result of successive epochs of dynamic action preceding the Pliocene lowland reduction, while the latter comprises the elevation of the Cascade lowland to form the Cascade plateau or the uplift of the Cascade Mountains.

In the Yakima region where the lowland surface is best preserved the history of Yakima River, as it can be traced out, corroborates the physiography as stated in the earlier section of this paper. The antecedent character of this river is at once apparent, and, as noted in the review of the literature, Russell was the first to call attention to this important feature. As can be seen from examination of Pls. II and VI, the Yakima crosses the high ridges in a deep canyon in which the original meanders of the river are strikingly preserved. The course of the river antedates the uplift of these ridges, and the warping of the lowland surface must have been effected at a rate that permitted the Yakima to maintain its course without change. That there was no damming sufficient to cause the stream to seek a new channel is shown very conclusively in the vicinity of North Yakima. The river leaves the broad transverse valley in which that city is situated by cutting through Atanum Ridge at Union Gap, which is nearly a thousand feet deep. Five miles east this ridge has a low saddle, purely structural in origin, which affords an easy pass less than 200 feet above the valley floor. Here, had there been any ponding of the Yakima waters during the uplift of the ridge, the river would surely have discovered the lowest point in the rim of the basin; but there is no trace of stream occupation of the pass. At other points where the Yakima cuts through other ridges the relations are hardly less convincing, since often the water gap interrupts the ridge in its highest part.

The surface upon which this course of Yakima River was established plainly must have been the Cascade lowland. The independence which this course shows of the hard and soft rocks which made up that lowland points to the development of the meanders on a surface on which there had been a perfect reduction to base-level.

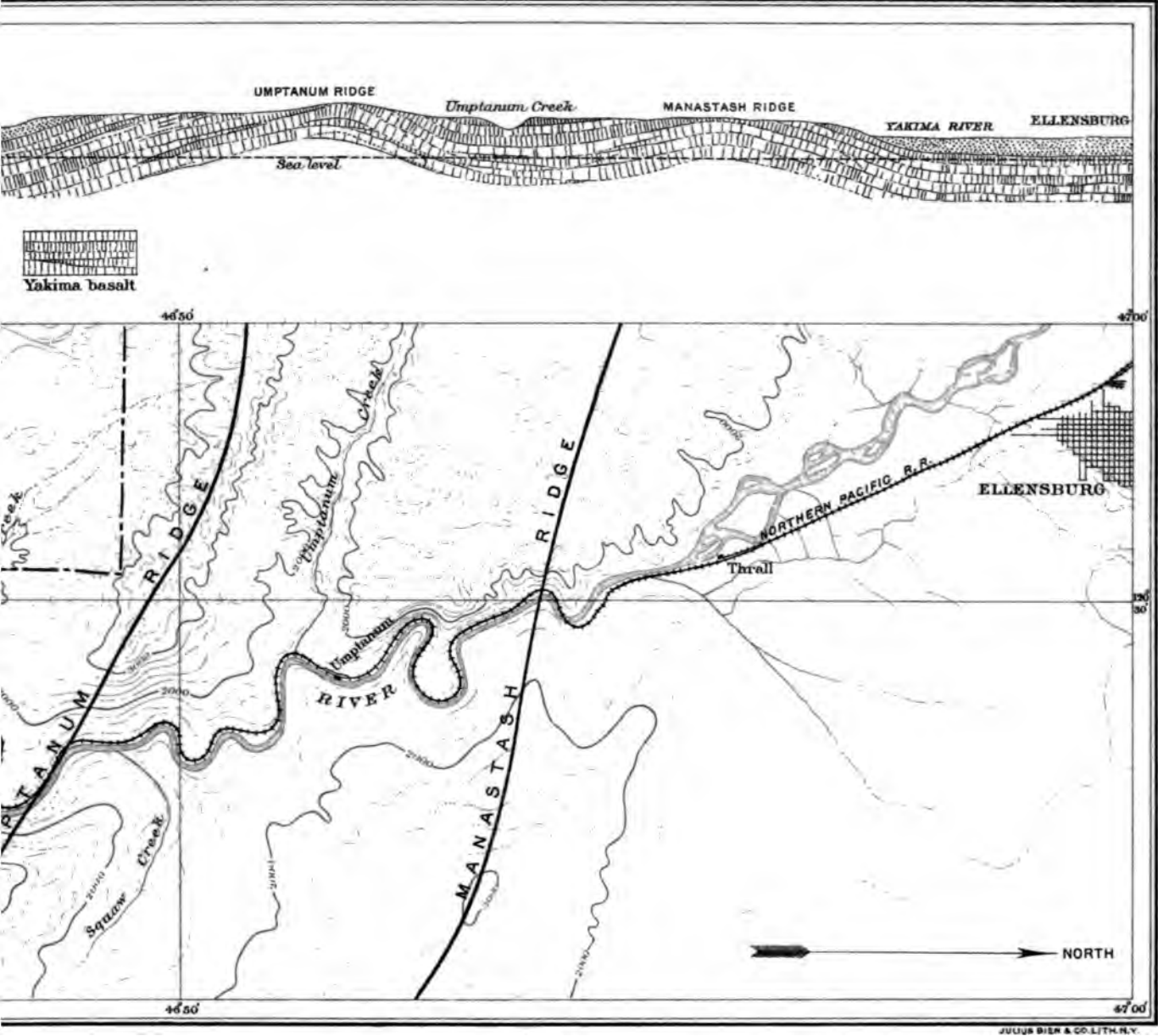
U. S. GEOLOGICAL SURVEY



SKETCH MAP OF THE YAKIMA CANYON, S
WITH PARALLEL GEOLOGIC SECTION, SHOWING

BY GEORGE S

1 0 1
S
Contour in



WING POSITION OF ANTICLINAL AXES
ATION OF WARPED SURFACE TO STRUCTURE
S SMITH

5 miles
200 feet

Furthermore, the manner in which the lowland surface cuts across folds involving the Miocene sandstone indicates that the course of the Yakima was not determined, at this time at least, by the slope of the uplifted lake bottom, as suggested by Russell. Here, again, the later warping must be distinguished from the earlier folding of the rocks.

Naches River, the most important tributary of the Yakima, is plainly also of antecedent character, since it has cut diagonally across one of the anticlinal ridges, uniting with the main river near the axis of the ridge (Pl. VI). The smaller tributaries of the Yakima in this region appear to be generally synclinal in position and also consequent upon the warping of the lowland. This statement, however, needs modification, since in the cases of Wenas and Selah creeks portions of the streams cut across minor ridges. Selah Creek also flows along the north side of Selah Valley in a canyon the brink of which is above and over a mile distant from the axis or lowest part of the valley. Such a relation may be taken as showing that the course of the stream is antecedent to only a portion of the warping of the lowland, the axis of that deformation having shifted southward. Wenas Creek is peculiar in that while it flows along the rather broad valley between Umptanum Ridge and Cleman Mountain and may be considered a synclinal stream, its shallow canyon is cut along the axis of a low anticline. This fold shows both in the rocks, the basalt appearing in the canyon, and in the deformation of the surface. The geologic and topographic relations of the Wenas Valley can be seen on the map of this area (Pl. IV). Back from the creek on either side is a parallel valley across which the seasonal streams flow before joining the creek. The old lowland surface can be traced from the slope of the ridge across the back valley and up on the flat-topped hills overlooking the main creek, and the fact that basalt boulders cover these hilltops where the underlying rock is sandstone shows that this is the lowland surface. At one place the back valley has so level a floor that a stream coming down from the ridge sometimes divides on its alluvial fan and flows out to the creek through two separate canyons. The explanation of these relations that presented itself in the field was that Wenas Creek was at first a synclinal stream in the valley between the two ridges, but by a later uplift of the low ridge along the center of this valley the creek cut down through the sandstone into the basalt beneath. There is evidence, too, that this later warping followed a structural line marked out at the time of the prelowland folding. The uplift of this medial ridge, a movement not exceeding 300 feet, was so gradual that not only did the main creek maintain its course but the tributaries suffered no changes, but crossed the unaffected back valley and cut steep-sided gulches through the uplifted ridge. A simultaneous and indeed connected uplift also occurred a few miles up the valley, where the two

northern branches of the Wenas cut across an arch of basalt. The structure here can be seen perfectly in the canyons, and the flat crest of the ridge well expresses the lowland surfaces; and here again the absence of conformity between surface and structure is noticeable. This history of Wenas Creek is simply an incident, of little importance except as it may show that the warping of the Cascade lowland was not a simple, uninterrupted movement, in some localities at least.

An interesting problem in connection with the history of the Cascade Range will be the identification of the system of antecedent drainage of which Columbia, Yakima, and Wenatchee rivers appear to be important parts. It will be at once noticed that these master streams are in no sense consequent upon the broad Cascade plateau with its north-south trend, as described by Russell, nor altogether upon such minor uplifts as have been thus far recognized. These rivers are the streams that controlled and effected the reduction of the post-Miocene land surface to a peneplain, and the study of this drainage system may yield some data bearing upon the degree to which the planation was carried and upon the position of monadnocks and important divides. The extent to which it is justifiable to apply this hypothesis of the deformation of the old lowland surface into local domes or ridges, features measuring a few miles in shorter diameter, rather than into a broad plateau uplift measuring hundreds of miles in extent, can then be better discussed.

PHYSIOGRAPHY OF THE SNOQUALMIE QUADRANGLE.

Since writing the foregoing portion of this paper the author has extended the geologic mapping westward from the Mount Stuart area. The Snoqualmie quadrangle, which was surveyed in 1902, lies within the heart of the Cascade Range, and includes about 50 miles of the main divide between the Puget Sound drainage and the streams tributary to the Columbia. Such a region appears to furnish an opportunity for testing the wider application of the conclusions reached in the adjacent area. In the Ellensburg quadrangle erosion has been insufficient to destroy the traces of the Pliocene peneplain, now warped into the ridges described in the preceding pages. In the Snoqualmie quadrangle land sculpture has plainly reached a stage in which no traces of such a peneplain can be recognized. The topographic cycle is nearing maturity, and while the problem of interpreting the physiography is more difficult, it becomes interesting to make the test and to attempt to determine for this portion of the range the type of uplift which inaugurated the present cycle of erosive activity.

As a preliminary to this, it is helpful to review certain of the general principles of land sculpture as first and most clearly defined by Powell and Gilbert. These will be briefly stated in so far as they apply to the question in hand, which is, What was the character of uplift of this central portion of the Cascade Range? Such general principles may be stated thus:

Degradation is controlled by declivity, rock structure, and climate. As will be seen below, the second and third factors may be omitted in the present consideration. While of great importance, they are essentially without value as criteria in this instance. Degradation, including erosion, sapping, and corrasion, as well as transportation, increases with declivity.

The work of ordinary degradation may be greatly augmented by glaciation, which, as will be noted later, was not universal in this area, hence glaciation has value for the purpose of this discussion.

In the case of the simple uplift of a broad arch, there would result a flat top and steeper flanks. On the steeper flanks the greater declivity would determine the locus of the more effective degradation. With consequent streams, therefore, the maximum rate of degradation would obtain along the flanks of the arch, and at any stage there would result an axial ridge with axial peaks as the highest portion of the uplifted area. This result may be stated differently, following Gilbert: There would be a persistence of divide, since at first it was the divide because an eminence, and later an eminence because the divide.

If the elevation was so slow in its first stages as to enable degradation to keep the axial region practically reduced, the resultant form would have a plateau character, as Powell has pointed out in the case of the western portion of the Uinta uplift. There, however, the axial region is higher, although its prominence is inconsiderable when compared with the whole amount of degradation.

With antecedent streams there is not the same persistence of divides, but rather a change due to the tendency of the streams to become more and more consequent. As developed by Campbell, the law of this migration of divides is that the divide tends to migrate toward an axis of uplift and away from one of subsidence. Thus it follows that in the case of a warped peneplain the antecedent drainage would tend to adjust itself to the warping and the streams would come to occupy the axes of relative depression with divides located upon the axes of elevation. In the case where the axis of depression shows changes in direction of pitch there would also be the tendency for the point on this axis, marked by divergence of pitch, to become also a divide.

Now, turning to the Snoqualmie area, certain facts of observation may be stated, as they apply to the problem under discussion.

The main divide of the Cascade Range within this quadrangle is wholly upon Miocene rocks, with the exception of 2 miles, where it is close to the contact of the Miocene with the Eocene. The highest peak on this divide, which has an altitude of 7,512 feet, and the lower portion of the divide for a considerable distance—with an altitude of 3,500 to 4,500 feet—are composed of Miocene volcanic rock with essentially the same physical characters. For this reason it appears evident that, as was stated above, rock character is not at all a controlling factor.

Climatic conditions are more or less uniform over this area, and any differences are dependent upon relative altitude, which in turn is involved in the question of relative uplift which is being discussed. Climate must therefore be left out of the discussion, and it is plain also that it would not have any important bearing on the final decision.

In the Lower Yakima region, where the river was antecedent, it was shown that the rate of uplift of the transverse ridges was not essentially more rapid than the rate of corrasion. The uplift, however, was greatly in excess of ordinary erosion, since many remnants of the uplifted surface remain. In the central region Yakima River carries its low-grade valley well back toward its head, so that the rate of uplift here has not been much greater than the maximum rate of corrasion. No actual remnants of the old surface, however, are known in this mountainous region, so that while degradation has far from kept pace with uplift, it has been efficient enough to produce a topography that has many characteristics of maturity. The question of the antecedent or consequent character of the drainage again depends upon the main question.

As can be seen on the accompanying map of the Snoqualmie quadrangle (Pl. VII), in which only the 500-foot contours above 5,000 feet are shown, the trend of the higher portions of the area is slightly north of west. The main divide has a general trend of a few degrees east of north, so that the difference in trend is approximately 90 degrees. Further, it will be seen that the high peaks on the divide are where it is crossed by these east-west heights.

The streams in the vicinity of the outlying heights are fully as efficient as those near the main divide, and in many cases possess the advantage of shorter courses and steeper gradients.

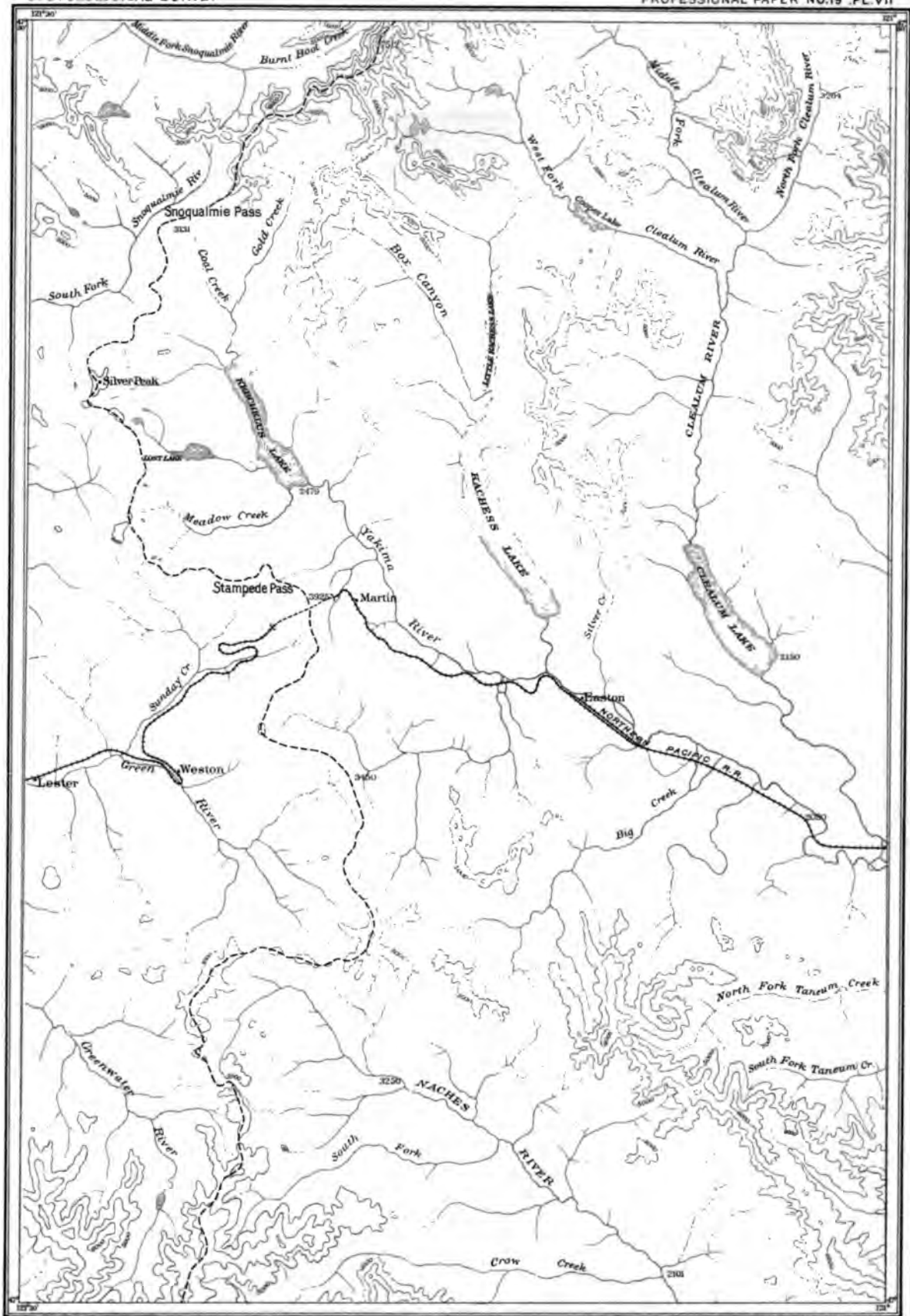
The thick mantle of soil which is of common occurrence in the lower divide region must be taken as strong evidence of the inefficiency of transportation here as compared with the higher country.

Glacial erosion has been an important factor in the northern area, characterized by a greater topographic prominence, while glaciation has been wanting in the lower parts of the main divide.

As the third part of this section, the foregoing general principles and particular facts may be brought together and certain conclusions deduced. This process will constitute the wider application of the hypothesis based upon the work in the Ellensburg quadrangle. The deductions are as follows:

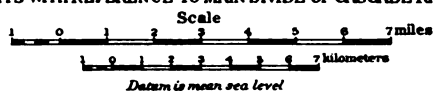
(a) Whatever the rate of uplift, the axial region should exhibit some topographic prominence. If uplift has outstripped degradation, as is the case in this area, the axial ridge must be a distinctive feature.

In fact, the main divide in the Snoqualmie quadrangle fails to show any such prominence, except as was noted above. Therefore it is not the axial region.



Topography from
United States Geological Survey
topographic map

MAP OF THE SNOQUALMIE QUADRANGLE, WASHINGTON
CONTOURS OF 5000 FEET AND ABOVE, WITH 500-FOOT INTERVAL, ARE GIVEN TO SHOW DISTRIBUTION
OF HEIGHTS WITH REFERENCE TO MAIN DIVIDE OF CASCADE RANGE





(b) Uniformity in present altitude of neighboring heights is suggestive of pre-existent uniformity, even if not exactly indicative of the actual position of the older surface. A line connecting closely adjacent heights, even although these are separated by canyons representing the work of efficient stream corrasion, is expressive of the position of an axis of uplift.

In the Snoqualmie quadrangle the position of three such axes of uplift may be approximately determined. The southernmost of these extends beyond the boundaries of this quadrangle, both east and west from the divide. Next, northward, is the high ridge between Naches and Yakima rivers, which is topographically and, in part at least, structurally the continuation of Manastash and Umptanum ridges to the southeast, which are known to represent upwarps of the old peneplain. Likewise, the third line of heights along the northern edge of the Snoqualmie quadrangle connects with the prominent Mount Stuart mass which constitutes the axial portion of the supposed Wenatchee upwarp of the lowland surface. These three lines of heights, which thus possess marked topographic prominence, are believed to indicate the position of three upwarps of the lowland surface.

How nearly the present surface on these heights represents the old surface thus uplifted can not be so definitely stated. On the highest portions of the Naches-Yakima ridge the level tops are strongly suggestive of the old surface. The uniformity in the present altitudes is a striking feature of the northwestern portion of the area, as illustrated by Mr. Willis on Pl. IX, and this uniformity may reasonably be considered the result of a general reduction of these tops, which has been relatively slight in amount.

(c) In whatever degree the system of divides fails to accord with the deformation, the drainage system shows similar lack of consequence. Streams cutting across lines of uplift must be antecedent, in part at least, and, with antecedent streams, the divides may be in process of migration.

In the Snoqualmie quadrangle the main divide has been shown to be not coincident with the axis of most marked surface deformation. Near the northern edge of the quadrangle the divide makes a sharp turn to the east and continues this northeastern trend for several miles beyond the boundary of the area described here. This trend coincides more nearly with the axis of uplift indicated by the east-west line of heights.

In the lower country of the Ellensburg quadrangle Yakima River is known to be antecedent to the warping of the peneplain and Naches River to be antecedent in a portion of its course and consequent in other portions. The history of the Puget Sound streams has not been studied.

It appears evident, then, that these two master streams may also have a mixed character in the Snoqualmie quadrangle. The Naches system is for the most part

consequent upon the two upwarps shown by the elevated ridges, and a relatively high portion of the divide is at its head where the downwarp between these two upwarps dies out. The most important tributary of the Yakima, Clealum River, appears to head somewhat north of the northern axis of uplift and is in that case antecedent. The Upper Yakima itself, however, plainly occupies an area of relative depression and receives consequent streams from the slopes of the upwarps to the north and south. There is some evidence, however, of partial inconsequence, but the position of the main divide which parallels for about 10 miles the upper course of Yakima River appears to be in part determined by the cross axis from which this downwarp pitches.

A drainage system consequent upon complex warping of this character is thus less symmetrical than one consequent upon a broad arch. The partial inconsequence expresses simply the effect of the antecedent character of these streams which was partially preserved wherever the rate of uplift or warping failed to be the determining factor. In general, however, it is quite possible that much of the antecedent drainage may have been consequent upon preeneplain structure, which was paralleled by this later warping, so that in the following cycle the antecedent streams have maintained their courses which may also appear to be consequent upon the warping.

The degree of agreement of the drainage with the surface deformation may furnish data for the separation of the uplift of the Cascade Range into distinct stages, as well as a more exact differentiation of the upwarps that constitute this uplift.

(d) The ultimate deduction is that, whatever the relative proportion of antecedent and consequent character in the drainage system, the main divide for the greater portion of its length in this area neither coincides with nor parallels the axes of most marked deformation of the preexistent surface. The uplift to which the Cascade Range owes its origin was not simple in type, but complex, and within this area can be resolved into three well-defined upwarps, which, moreover, are transverse to the main trend or major axis of the range considered over the larger area to the north.

RÉSUMÉ.

In the central Washington area detailed mapping has given data for the recognition of a lowland surface, the fixing of the age of its development as Pliocene, the suggestion of the drainage system which controlled that reduction to a peneplain, and the determination of the kind of deformation to which this lowland surface was later subjected. Such evidence has its bearing upon the broad problem of the origin of the great plain of the Columbia and the Cascade Range. To the east, deformation of the lowland has been less marked, while on the other side erosion has largely destroyed the uplifted peneplain. Future investigation may be productive of

corroborative evidence over a larger area. The evidence in hand, however, is believed to be sufficient to prove the youth of the Cascade Range and to suggest that the general type of its uplift may have been complex rather than simple.

The data furnished by this study of the geology and physiography of central Washington may also have a bearing upon broader problems. The eventful character of Tertiary history in this province is noteworthy, as showing the rapidity with which geologic processes may accomplish their work. The Eocene section measures not less than 10,000 feet in thickness and is divisible into four distinct formations, separable both by physical breaks and by differences in fossil floras. In the Neocene period not only was there the great volcanic activity and the later deposition of the Ellensburg sediments, but also widespread deformation and the production of an extensive peneplain were effected.

Another feature of general interest is the deformation this peneplain has subsequently suffered. The evidence is believed to be conclusive that the old lowland surface has been warped so as to form anticlinal mountain ridges and synclinal valleys. Elsewhere no such striking instance of peneplain modification has been described, and this unique character of the area is doubtless to be attributed in part to the structural characteristics of the jointed sheets of basalt involved in this deformation. Connected with this warping of the peneplain is the antecedent character of Yakima River, which serves as an exceptionally fine example of that type of stream in that it has maintained its course across not only one but several uplifted ridges.

A third principle that demands recognition is the importance of separating the results of two or more distinct periods of deformation. In this way only can there be any true interpretation of structure in cases, such as the Yakima region, where the later movement largely followed the axes of earlier folding. Subsequent work in the Cascade Range has strengthened the belief that such persistence of structural lines through successive epochs of deformation is not at all exceptional and must not be overlooked.

The results of this physiographic study promise to greatly facilitate future work in the northern Cascades, but they have also been presented here with the belief that they contribute somewhat to our understanding of peneplains and their subsequent modification, with the resulting difficulties attending their recognition and identification.

CONTRIBUTIONS TO THE GEOLOGY OF WASHINGTON

PHYSIOGRAPHY AND DEFORMATION OF THE WENATCHEE-CHELAN
DISTRICT, CASCADE RANGE

BY

BAILEY WILLIS

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PHYSIOGRAPHY AND DEFORMATION OF THE WENATCHEE-CHELAN DISTRICT, CASCADE RANGE.

By BAILEY WILLIS.

INTRODUCTION.

The following article is based on observations made during several excursions in the Cascade Mountains from 1895 to 1900, inclusive, and upon discussions with Messrs. I. C. Russell and George Otis Smith, to both of whom the writer is much indebted. When engaged in exploration in the same province, between 1881 and 1884, the writer took little note of the physiographic aspects as such; to him they were then scenic aspects only, and impressive grandeur was the dominant idea they left. But upon returning in 1895, after eleven years spent in the Appalachians, the case was different. Association with Gilbert, Davis, Hayes, and Campbell in the discussion of physiographic relations of the eastern region prepared the observer to see the less evident, but not less definite, facts of the western province.

In 1895 the writer traversed the western slope of the Cascade Range from Mount Rainier to Skagit River, visiting especially Snoqualmie Pass and Monte Cristo. At the former place the diversion of Snoqualmie River by a moraine dam is a conspicuous fact. The former eastern course leads by a wide valley to Lake Keechelus, but the diverted stream is now cutting a precipitous canyon in the western slope. The discovery of fossil leaves, classed as Miocene by Knowlton, in graphitic slates in the crest of the pass suggested the post-Miocene uplift of the range. Near Monte Cristo wide general views were obtained, which swept the sky line from southeast by south and west to northwest, and it was apparent that many jagged peaks rose approximately to uniform altitudes, which might reach or fall little short of an ancient plain. Stratigraphic studies of the Puget group of Eocene and Miocene strata led the writer tentatively to assign this hypothetical plain to a late Miocene date, and to place among the latest events of the Miocene epoch the uplift by which the old lowland was raised to a position at or above the summits of the Cascades.

To test the validity of these inferences, during succeeding years the heights and slopes of the range were viewed from many points, and the intersecting lines of sight, leaping from peak to peak at nearly uniform altitudes, were thought to define clearly the general attitude of the ancient plain. Among the panoramic views upon which this hypothetical reconstruction of a vanished surface was based may be mentioned that from the eastern side of Mount Rainier, at 7,500 to 10,000 feet above sea, looking east and north; that from a spur (6,000 feet) of Huckleberry Peak at the head of Gold Creek in the northeastern corner of the Snoqualmie quadrangle, tracing the sky line throughout the entire circle except from northwest to north; that from Stormy Mountain (7,219 feet) in the Chelan Mountains in the western quarter of the Chelan quadrangle; and that from Boston Mountain (8,300 feet) north of Cascade Pass at the head of Stehekin Valley.

In the meantime, in 1897-98, Russell reached the conclusions expressed in a preliminary paper on the geology of the Cascade Mountains in northern Washington^a in the following terms:

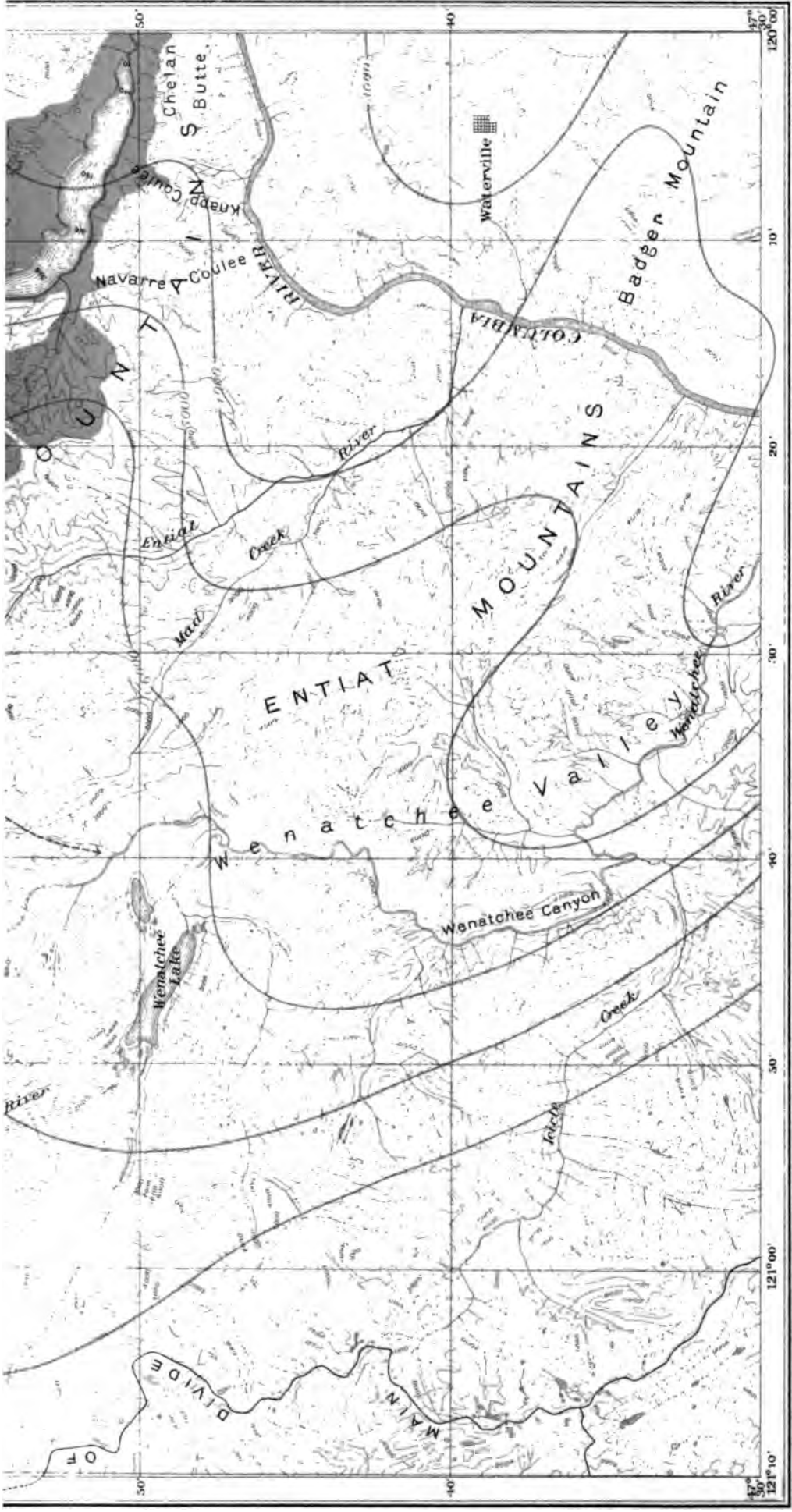
"After the time of long-continued erosion referred to above, when the Cascade region in northern Washington was reduced to a peneplain, there came a time of elevation, when the peneplain, or a very large portion of it, was bodily raised some 7,500 feet at least, and thus became a plateau. In a broad view of the region this Cascade plateau may be considered as of the nature of a broad, flat-topped anticline, or, as Dana would probably have called it, a geanticline. The rocks composing this uplifted region had previously been folded, but we are justified in assuming, on what may be said to be general principles, that renewed movements occurred along these old structural lines. The main change was a general rise of a region of some 10,000 or 15,000 square miles. The total area affected was much greater than this, as the Cascade plateau extends both north and south of the field under discussion.

"One of the most remarkable features in the relief of the Cascade plateau is the seeming nearly level character of its original surface. The uprising was effected without pronounced tilting. Perhaps, when our knowledge is more extended, it will be found that this conclusion is too hasty, but at present, from a study of the distribution of the rivers, as well as of the heights of the peaks left by erosion, it does not seem that the plateau had a decided, if any, inclination toward either the east or the west. This is the most marked difference between the Cascade plateau in northern Washington and the Sierra Nevada. The Sierra Nevada, as we now find it, is the result of the erosion of a tilted plateau, bordered on the east, from Owens Lake to Mono Lake at least, by a great belt of branching fractures and faults. No such belt of fractures and displacements parallel with either border of the Cascade plateau is known. The evidence is that the rise from each side of the plateau to its nearly flat summit portion is gradual."

Among the services rendered the writer by George Otis Smith was that of well-maintained skepticism in regard to recognition of an ancient plain over the Cascades.

^a Twentieth Ann. Rept. U. S. Geol. Survey, pt. 2, pp. 144-145.





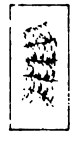
MAP OF THE WENATCHEE-CHELAN DISTRICT
CASCADE RANGE, WASHINGTON

Physiography by
Bailey Willis, Geologist



Contour interval 1000 feet

LEGEND



Existing glaciers



Former extent of Chelan Glacier
Similar glaciers occupied Methow
and Wenatchee valleys but their
limits are not determined



Contours on the warped surface
of the Methow (Pliocene) pene-
plain as restored hypothetically
where eroded

He asked for demonstration, which was difficult, since the suggestions of panoramic views failed to convince, but during his field work of 1900 he himself supplied the evidence of the existence of an old base-level plain on the hills of Yakima Valley, as stated in the first part of this paper. Of these results the writer was aware when he took the field in August, 1900, and he has found them of much value in tracing out physiographic relations in the vicinity of Lake Chelan. It would seem that the principal episodes in the history of the Cascade Mountains may now be stated with confidence.

In the field work of 1900 the writer was fortunate also in having the company of Prof. R. D. Salisbury, and statements concerning the glacial phenomena were suggested chiefly and often wholly by his observations and interpretations; but he is not responsible for the form in which they may here appear. The profiles which illustrate this article are drawn from topographic maps of the Chelan and Methow quadrangles, surveyed by Messrs. Griswold and Farmer, topographers of the United States Geological Survey. The writer has traversed much of the region with their maps in hand, and places confidence in the excellence and detailed precision of their work.

PHYSIOGRAPHY.

DESCRIPTIVE ANALYSES.

COLUMBIA GORGE, WENATCHEE TO CHELAN.

COLUMBIA CANYON.

The broad flood of Columbia River emerges upon the valley about Wenatchee from a noble gateway in the Entiat Mountains. The elevation of the river is somewhat less than 700 feet above sea. On the east the slopes of Badger Mountain rise to 4,200 feet, from which altitude the long, even profile of the summit declines gently eastward; on the west of the stream peaks of the Entiat Mountains in sight attain 5,700 feet, and these are the foothills of the Cascades. These heights of 3,500 to 5,000 feet that thus hem in the river spring from a flood plain one-half to three-quarters of a mile wide, and the profiles swing upward in convex curves, steepest near the foot. The effect combines grace and grandeur, the wide river, the broad gorge, and the great mountains harmonizing in their proportions.

Such is the view from a little distance. Upon entering the gorge the observer who follows the road along the western bank feels more closely shut in. On the one hand it is but a leap into the dark-green river swirling past fallen blocks of gneiss; on the other the cliff is near, and its crest, 1,000 to 1,800 feet above, is impressively high. The boldest profiles occur from 4 to 7 miles above Wenatchee, and one conspicuous point—Ribbon Bluff—with precipitous face projects into the gorge 12 miles farther upstream, 3 miles above the mouth of Entiat River.

Cliffs are not, however, the most characteristic features of the gorge. Along the eastern side they do not occur conspicuously, and even on the bolder western side they give place frequently to steep slopes in which rocky ledges project sharply through scanty grass and sagebrush. These steeps terminate above in points of long spurs, which rise westward with gradual slope to the highest summits of the adjacent mountains. The prominent angle between the steeper and gentler elements of the profile is an important physiographic feature, upon which broad deductions are based.

CHELAN BUTTE.

Looking upstream from near Ribbon Bluff, the view includes a summit higher than its fellows on the west bank and peculiar in the long sweep of its spurs in a concave curve from the top to within 800 feet of the Columbia, where the slope breaks off into the gorge. This is Chelan Butte (3,892 feet), the eastern end of a ridge which lies between the Columbia and Lake Chelan. Its graceful profile presents the first view had from within the gorge of those higher topographic elements which lie between the mountain tops and the steeps that shut in the river. The fact that this profile descends from Chelan Butte to within 800 feet of the river, whereas in the Entiat Mountains it ends 2,400 feet above the stream, is an index of the relative amount of recent uplift in the two places.

The graceful silhouette of Chelan Butte is broken near the extreme summit by sharp, rocky ledges, which support a narrow but flattish crest. They are formed by granite dikes cutting the softer gneiss. Peaks of this partially cliff-girt form occur isolated but dominant among the mountains west of but near the Columbia, and will hereinafter be referred to as monadnocks upon the Methow plain,^a the remnants of which, so far as recognized in this region, will be described later.

THE EASTERN BANK.

The eastern side of the gorge differs markedly from the western. Not only is it in general not so bold of profile, but the forms of the slopes are genetically distinct. For a few miles above Wenatchee the bluffs on the east of the river almost equal those on the west in height and boldness where they rise to Badger Mountain; farther upstream, however, the slope recedes gently from the river, and, growing steeper, ends 2,000 to 2,300 feet above the stream in a mural escarpment 150 to 300 feet high. This wall crowning the height is the edge of a sheet of basaltic lava whose dark-brown color and columnar structure give it emphatic value in the otherwise gray and tawny landscape. In general the summit is even and nearly level, it being the western margin of the plateau of eastern Washington, and the line of the escarpment

^a Cascade plateau, the term used by Russell to designate the surface which might be restored over the Cascade Range, would be used as the name of the peneplain, but its prior use (1872) to denote a stratigraphic series renders it unavailable. Methow peneplain is therefore here applied, from an important spur of the Methow Mountains, in which the old level is well exhibited.



VIEW OF HIGH CASCADES FROM HEAD OF GOLD CREEK, SHOWING UNIFORMITY OF ALTITUDES.

is in sympathy with other level lines that cross the slope at various altitudes. Some of these lines are terraces due to landslides, others in ravines are terrace-like embankments that may be traced to the work of glaciers, and others much more continuous and nearer the river are stream terraces of the great Columbia itself. These last are represented on the western side of the gorge also.

Among the features which in any complete account of the region should be fully described are the several types of terraces of this eastern side of the gorge—the landslides, most common where the heavy columnar mass of basalt weighs upon the underlying schist and granite; the ice-built terraces, which are in part effects of tiny glaciers that gathered in the shaded lee of the plateau, in part results of occupation of Columbia Canyon by a tongue of a large glacier which, descending from the north, flowed down the river to a mile below Chelan Ferry; and the river terraces that extend for miles along the stream, their even tops sloping down its course and their perfect embankments rising near Chelan Ferry as much as 600 feet above the water. But all these features belong to a chapter of the history which is herein touched only incidentally—the very recent episode of glaciation.

BADGER MOUNTAIN AND WATERVILLE PLATEAU.

In its great sweep westward, southward, and southeastward across Washington Columbia River marks out the central plateau of the State. Most elevated near its western margin, this highland slopes in a general way east and southeast, and it is diversified both by channels and by uplands. The former, such as Grand and Moses coulees, appear to have been canyons of a large stream, probably the Columbia, but they are now nearly dry. The uplands are elevated portions of the plateau, connected with the lower parts by continuous slopes, usually not distinguished by scarp or steep.

Badger Mountain and the Waterville plateau are parts of this central district, situated at its extreme western margin and separated from the eastern foothills of the Cascade Range only by the canyon of the Columbia. It will appear later that there is in fact no separation in the sense that the mountain district west of the river has had an orogenic history different from that of the plateau east of it. But the rock structures and conditions of sculpture are so unlike that the two provinces appear at first sight to be physiographically and geologically distinct.

In the vicinity of Waterville the plateau presents an undulating surface, with a maximum but very local relief of 200 feet in a tenth of a mile. Well-defined but shallow drainage channels converge southeastward from a flat divide at 2,900 to 3,000 feet above sea. They constitute the headwaters of Moses Creek, which soon falls into a newly cut ravine. There was no water in any of the head streams in August, 1900, and the flow is not only intermittent but never large. The surface is deeply

mantled with fine soil, derived from decay of the underlying basalt. Active corrasion would quickly gully and remove it. The surface forms are rounded and filled out by blown material, showing that wind rather than water is now the efficient modeling agent; yet the landscape as a whole presents relief due to stream work.

In the flat spaces about the margin of the plateau, in the even divide between Coberly and Moses creeks, and in table hills southeast of Waterville, there are areas of considerable extent which are not now being eroded by streams. They present flattish surfaces, due to earlier low-level erosion, and are herein correlated as remnants of the plain once cut upon the basalt surface. From these remnants this plain is traced into the Cascade or Methow plain recognized by Russell.

Badger Mountain appears as a long, low hill when seen from the north from Waterville plateau. Although it rises 1,400 feet above the plateau, its slopes are so gentle, its surface so smooth, its length so extended, that it does not appear to be more than a hill. The summit is broad and flat, and long spurs with even slope extend not only northward but also southward several miles into the high valley of Rock Island Creek. Only when seen from the depths of the Columbia gorge or in relation thereto is Badger Mountain impressive, as toward the canyon it generally presents one or more mural escarpments of basalt crowning a confusion of landslide terraces, and it is conspicuous in height and mass.

The details of relief cut in its northern and southern slopes are more marked than those of the Waterville plateau, as might be expected from their steeper grade; but they are not accented by rocky walls, as are the similar features of Moses and Coberly creeks. Careful study of the two slopes of the mountain in riding across it discovered no conspicuous rock outcrops on the north or south. In the district of basalt flows, in which Badger Mountain lies, outcrops are rare where the dip of the basalt sheets and the surface slope nearly or quite agree; the outcrops are, on the contrary, conspicuous and continuous, like terrace walls, where a gentle dip of the sheets is beveled by a steeper surface slope. It is inferred, therefore, that the basalt sheets conform in a general way to the arched surface of the mountain, as they do to the surface of the Waterville plateau and of the synclinal valley of Rock Island Creek.

When the physiographic features of the mountain are compared with those of the plateau they are found to be very similar if not identical. In the plateau there may be recognized flats of an old lowland and later slightly developed relief. On Badger Mountain the flats may be identified in surfaces of long unmodified spurs and in the level summit, while the later relief appears more decidedly developed, but of the same stage as that of the plateau. The mountain therefore appears to be a part of the plateau, raised to a greater elevation without interruption of the slope. In consequence of altitude and accented grade, the mass is undergoing more rapid corrasion than the adjacent plains of like rock, but the process of dissection has made

very little progress. Hence we may infer comparative inefficiency of the process or recency of relative uplift, or both.

TRIBUTARIES OF THE COLUMBIA.

The traveler following the eastern bank of the Columbia crosses but a single stream, Coberly Creek, whereas along the western bank from Wenatchee to Chelan he encounters in 35 miles six streams, of which three are rivers. This distinction is not limited to the short stretch under consideration, it being true of the Columbia throughout central Washington. From Spokane River to Snake River, 275 miles, no tributary of noticeable size enters from the east, while seven large rivers come in from the west. On the one side is an arid plateau; on the other, well-watered mountain systems.

Wenatchee River, Lake Chelan, the independent streams between them, and their tributaries drain approximately 30,000 square miles of high, mountainous country, which receives for the most part very heavy precipitation. The volume of water which they contribute to the Columbia is accordingly large. The three dominant rivers are Wenatchee, Entiat, and Chelan. Their courses are practically parallel, and at first sight, as stated by Russell,^a appear to be simply consequent upon the surface slope of the uplifted Cascade Plain. Evidence will be given later to show that Chelan is a composite stream, made up of several parts united by piracy; and it is probable that Entiat also consists of parts of what were formerly distinct streams. The history of Wenatchee River is not made out in detail, but it has a wider branching system than the others, and may, like them, be a composite river. Reason will be shown later, however, for considering it an older river than Chelan, and one which has lost to the Chelan system an important part of its headwaters. The Yakima and Methow systems appear to be equivalent to the Wenatchee in age and general history, and these three may be classed with the Columbia as representing a drainage system from which the existing one is derived by adjustments.

The several valleys which join the Columbia from the west between Wenatchee and Chelan may now be appropriately considered.

WENATCHEE VALLEY.

Wenatchee Valley is developed on a mass of arkose sandstone lying between harder granite and gneiss. Whatever the antecedent conditions of drainage, adjustment to this soft mass and opening of a wide valley must result in time. The degree of adjustment attained and the extent of the valley appear to be such as to show that there has been adequate time. In one respect, however, the river exhibits an eccentric course. After flowing some miles southward in the sandstone area, it turns abruptly westward and crosses into the adjacent granite on the west. Russell^b

^a Twentieth Ann. Rept. U. S. Geol. Survey, pt. 2, p. 146.

^b Ibid., pp. 140 and 158.

describes the depth of the canyon which the river has cut in granite as 3,000 feet, and the length 6 miles. An interesting problem is thus presented, and several alternative hypotheses occur in explanation. First, there is the idea that the meandering river was superimposed upon sandstone and granite at a time when their surfaces came to a common peneplain.^a In this view the eccentricity is an original feature which adjustment has not yet modified. Second, the broad valley which exists in the sandstone may be looked upon as the original course of Wenatchee River, and the eccentricity of the present channel may be ascribed to diversion. A possible cause of diversion may be found in glaciation. As described by Russell, the Wenatchee glacier once filled the upper valley as far down as a point abreast of the present entrance of the river into the granite canyon. Under appropriate topographic conditions the ice might be competent to carry a stream flowing on its western margin over a divide into a small ravine adjacent, and thus the conditions for development of the present relations might be established. The fact that Upper Wenatchee River flows along the western side of its broad valley lends color to the hypothesis.

At present a low divide crosses the sandstone area south of the elbow which carries the Wenatchee into the granite. The divide is so low that it does not interrupt the view up the valley from Leavenworth, and its sky line falls in with the general elevation of neighboring hills of sandstone, while all such hilltops lie much below the granite and gneiss mountains on either hand. It is this view of a continuous valley which suggests the hypothesis of a formerly straight and now diverted course of Wenatchee River. The divide, nevertheless, requires explanation. Its elevation above that part of the valley upstream from it is a condition which could have resulted only from degradation of the upper valley, since the Wenatchee ceased to flow straight south across the divide. The depression of the upper valley may have occurred (a) through post-Glacial work of the diverted river; (b) during a glacial epoch through ice erosion by the Wenatchee glacier; (c) in interglacial time by degradation due to the diverted river, provided the stream was turned into the granite area during an earlier glacial epoch than that which is well known by its evident and widespread phenomena. Two epochs of glaciation are recorded in separate tills (the Admiralty and Vashon tills) in the Puget Sound Basin,^b and the glaciers were there confluent from the Cascades, yet in the area of glacial erosion records of one epoch only have been found. It is possible that general uplift and erosion were incidents of an interglacial time and that the earlier glacial sculpture and deposits have been largely obliterated. Detailed study of the profiles and gravels of Wenatchee Valley and Canyon may throw light on the problem of two glacial epochs.

^a Twentieth Ann. Rept. U. S. Geol. Survey, pt. 2, p. 140.

^b Willis, Bailey, Drift phenomena of Puget Sound: Bull. Geol. Soc. America, vol. IX, pp. 111-162



VIEW OF HIGH CASCADES FROM NEAR CASCADE PASS, SHOWING UNIFORMITY OF ALTITUDES.



The effects of deformation which are described in the last sections of this paper may also be considered in this connection, and the area about Wenatchee Lake may be found to have been depressed or warped down relatively to the lower valley.

ENTIAI VALLEY.

Entiat River is a small stream among its fellows. It lies between Wenatchee and Chelan rivers, and its drainage basin is surrounded by the basins of these streams, which join around its head and cut it off from the high glacier-bearing district of the Cascades. The stream is about 35 miles long and has a straight course (S. 28° E.) to within 3½ miles of its mouth, where it turns east to the Columbia. The valley is very symmetrical and is limited by the parallel Entiat and Chelan mountains.

The Entiat flows in a deep gorge, comparable in form with, but narrower than, that of the Columbia. Near its mouth the steep slopes are about 1,500 feet high, and on the south, up to 2,600 feet above the river, the tributary ravines are sharply chiseled. North of the stream and 1,900 feet above it begin gentler slopes and broader features, which are connected with those that lie above the inner gorge of the Columbia. Up the Entiat, about the junction with Mud Creek, the canyon appears to be but 1,200 feet deep and near Stormy Creek not more than 1,000 feet. These differences are coordinate with the grade of the Entiat, which from Stormy Creek to the Columbia falls 950 feet, and thus sinks that much deeper below the practically level contour of the base of the outer gentle topographic forms.

Three miles above Stormy Creek the Entiat Valley bottom is half a mile wide and the slopes of the canyon are continuously steep for 3,500 feet up to the closely adjacent summits of Tyee Mountain and the Chelan Mountains. This phase of the gorge is related in aspect and position to the section of Lake Chelan above Twenty-five Mile Creek. Each presents the appearance of a youthful canyon modified by glaciation, and their development will be further discussed in stating the history of Lake Chelan.

The position of the Entiat Valley does not appear to be due to any zone of rocks weaker than others so far as the distribution of rock masses is known by examination of float in the river near its mouth and by traversing the Chelan Mountains. The area is one of gneisses and intrusives, probably related in intricate manner. The rocks of the crest of the Chelan Range are, indeed, dikes which are relatively hard, and the divide is determined by them; the Entiat Range may be similarly crested; but these dikes of hard materials are not confined to the summits. They presumably occur irregularly within the Entiat Basin.

A simply fortuitous condition might determine the position of a minor valley like that of the Entiat between two larger ones, but there are some reasons for

believing that chance has not been a dominant factor in this case. It will be shown that the Entiat Mountains are located on an uplift, which was there more pronounced than along adjacent lines. The trend of this uplift is northwest-southeast, and it now limits the Entiat drainage basin on the southwest. The Chelan Mountains are probably along a similar line of uplift. Thus the Entiat Basin apparently occupies the position of a depression between two uplifts, possibly a downwarp valley.

The stream is, however, older than the most recent earth movements which have affected its present course. The uplift of the region in general, and of the Badger-Entiat Range in particular, occurred in two distinct episodes, and the first limited the Entiat Valley. The river appears then to have flowed straight to the Columbia. Its old channel is marked by the gap in the spur southwest of its present mouth, the gap which is shown on the topographic map at the contour of 2,600 feet, and which is 1,100 feet below the hilltop that rises northeast of it. The interpretation is that the stream was checked by the later movement on the Badger-Entiat axis, and was diverted to a new course, its present easterly one. It has since then cut its inner canyon down 2,000 feet below the old one.

NAVARRE COULEE AND KNAPP COULEE.

Navarre and Knapp coulees are unlike ordinary valleys in several respects. First, they carry no running water, except that from a spring which in each flows out near the level of the Columbia, at the foot of a gravel terrace. Second, the rivulets that now flow from beneath the gravel filling and which gather from gulches tributary to the main coulee are disproportionately small when compared to the valleys they occupy. Third, the canyons which constitute their present upper sections continue beyond the divide and extend into the Chelan Basin. Fourth, they have wide, flat floors of gravel, the one 400, the other 600 feet above the Columbia. This gravel filling appears as a conspicuous terrace when viewed from the eastern bank of the Columbia. Fifth, the wash from the adjacent hills is so copious that alluvial cones are built clear across the flat-bottomed coulee, and thus sections of it are converted into hollows, which occasionally hold water and accumulate sediment.

In cross section the two coulees are miniatures of the Columbia gorge. Each exhibits a narrow valley or canyon within a wider valley and thus records episodes of development which are directly related to those of the great river. Like the Columbia, Navarre stream and Knapp stream had their beginnings back in the time of the ancient plain whose remnants barely survive in neighboring heights. Navarre was always much larger than Knapp, and its features are more conspicuously developed.

From the Columbia the ascent to Navarre Coulee is by a sharp V gulch, beyond which one rides out upon the surface of the gravelly flat 400 feet above the river



VIEW IN NAVARRE COULEE.

(see Pl. XI), and for 5 miles may follow the level bottom. One then enters a narrower canyon, marked on the west side by a conspicuous vertical wall of granite 800 feet high, and in three-fourths of a mile passes through this gate into a pretty glade lying level between wooded slopes. The head of this glade is an amphitheater, little more than 300 yards in diameter and steeply hemmed in. It is silent now save for the sighing of the pines, but at its farthest point is the vacant site of a cascade, whose voice once resounded from the surrounding hills. The fall was about 150 feet and the volume of water was large. The stream was a river flowing from the Chelan glacier, and by this pass the great mass of gravel which fills the lower canyon entered Navarre Coulee. At the end of the latest glacial episode the ice sank within the Chelan Basin and the river found a lower eastern course. The cascade, however, is only the latest incident in the history of the valley. Before the ice time Navarre stream had cut the inner canyon and before that the outer valley.

Above the cascade's vacant channel, as one rides out upon a gravel terrace from which the slope descends 600 feet to Lake Chelan, the emphasis of the environment is upon the recent glacial condition; but reverting to the earlier history one finds no apparent source of the older stream. The valley is cut clear through the divide and ends in the air high above any streams which might once have been its headwaters.

Knapp Coulee closely resembles Navarre, but on a smaller and less emphatic scale. Near its southern end and western side bare rocks rise boldly in the face of the gravel terrace below the channel of the latest glacial stream and formed the sill over which the cascade dashed. Northward and 500 to 600 feet above the Columbia the surface of the gravel terrace extends 2 miles to a narrower section, which corresponds to the conspicuous canyon of Navarre, and by this pass the open slope above Lake Chelan is reached. Again the valley is cut through the divide and at least 400 feet below it, but the headwaters of the stream which accomplished the task have been so diverted to lower channels that they can no longer flow through the pass; indeed, they can no longer be positively identified, except that they must now be tributary to Lake Chelan.

The history of these coulees is thus seen to comprise in order (1) an early stage of valley development at a surface now above the 2,000-foot contour; (2) a phase of canyon cutting, which was sharply accentuated in a space just south of the Chelan Basin; (3) the diversion of the headwaters; (4) the reoccupation of the channels by glacial streams, which, being heavily overloaded, filled them with gravel; (5) their present condition, in which they are being aggraded by wash from the steep side slopes, and reexcavation has begun in gullies facing the Columbia.

These incidents of individual history, especially the accented canyons and diversion of headwaters, fit in with other evidences in the interpretation of the character and distribution of deformation of the region.

LAKE CHELAN.

Lake Chelan is a slender body of water 65 miles long, whose southeastern end lies open to the sky between the grass-grown hills of the outer Columbia Valley, while its northwestern lies in shadow between precipitous mountains in the heart of the Cascade Range. There are sandy shallows near its outlet, but beneath the cliffs of its upper course the water is profoundly deep.

In brief technical phrase, the lake basin is a canyon modified, deepened, and dammed by glaciation. The canyon is that of the Stehekin-Chelan River, which rises in latitude $48^{\circ} 30'$ in glaciers of the Cascade Range at altitudes of 5,000 to 8,000 feet. The headwaters descend very abruptly, 1,000 to 1,800 feet in the first mile below the glaciers, and combine in a U-shaped valley of gentler grade, the fall being 2,500 feet in 23 miles. This section is cut in rock bottom. For 12 miles farther downstream the valley is floored with boulders, coarse gravel, and sand, and the slope is but 20 feet to the mile, ending in the delta which the stream is building into Lake Chelan.

The gravel-filled section of the valley is no doubt deeply cut in the solid rock, since but a short distance beyond the front of the delta the lake is more than 500 feet deep. For a distance of 35 miles the depth varies from 1,000 to 1,400 feet, 1,419 being the maximum as yet sounded. As the water surface is but 1,079 feet above sea, the bottom of the lake is for a short stretch 300 feet below sea level, and an interesting question is raised as to how so deep a basin originated. Fifteen miles from its outlet the lake begins to shallow, and in its lower reach does not exceed 200 feet in depth.

The water is retained at its present level by a dam of sand and gravel, which in the section exposed by Chelan River is seen to consist of several successive members, i. e., soil, coarse stream gravel, till, very coarse gravel in pockets or channels, and cross stratified sands. The base of the drift is not exposed. This drift dam fills the preglacial valley by which the Stehekin-Chelan River once reached the Columbia, and the present outlet turns from the drift into the gneiss and granite south of it, and has there cut a deep rock gorge.

The topographic environment of Lake Chelan presents several distinct phases. (See Pls. I and XIII.) About the eastern end the general aspect is that of a wide, open valley bounded by hills 1,500 to 2,500 feet high. The slopes are marked by long, low spurs, whose profiles rise moderately, but with increasing angle upward to the summits. Slight hollows between them have consistent grades. The surface is that of mature topography characterized by profiles which are concave upward, but on traversing the hilltops one notes in their flattish and rounded forms that the stage of maturity is not everywhere completely developed, else the ridge crests would be sharp, and sympathetic with the active corrasion of the slopes. The earlier phase is not, however, distinctly traceable in these summits.

Upon this mature surface are cut and built certain younger features. Where the major spurs sweep downward to the level that once was the valley floor and become gentle in slope, they end abruptly in steep or precipitous facets which break directly down to the lake shore and are about 400 feet high. These bluffs might readily be attributed to ice erosion, in view of the conspicuous evidences of glaciation in the Chelan Basin, but they are traced and correlated with the steeps which wall the inner gorge of the Columbia below the limit of any glacier, and they therefore are similar elements of the Stehekin-Chelan canyon which was cut within the mature topography of an earlier date.

Terraces which fill the hollows and occasionally skirt the slopes for some distance occur at various levels up to 1,100 feet above the lake. Their topographic position, relations among themselves, and constitution show that they formed in lakelets confined on the hillside by spurs and on the now open side by the glacier which occupied the Chelan Basin. A full discussion of them belongs to the glacial history of the region.

In the view from Chelan Butte northwestward, the lower section of Lake Chelan is seen for a distance of about 15 miles to occupy the wide basin just described. Its trend in this stretch is north by west 8 miles, and thence due north 7 miles. Along the western side of the latter reach runs a bold ridge, whose even crest is 3,600 to 4,200 feet above the lake and whose eastern face descends precipitously nearly to the water. A marked feature of its scarp is a deeply stained surface, freshly exposed, which is locally known as Red Slide. The lake trends westward around the northern end of Red Slide ridge and disappears from view among lofty mountains. The Methow Range lies north, the Chelan Range south, both rising to more than 7,000 feet above sea within 5 or 6 miles of the lake, and both sending out long, high spurs which maintain altitudes of 6,000 feet above sea to within 2 miles or less of the lake. From these spurs descend very steep slopes, scored by little ravines and worn by glacial action.

Sunk deep among the mountain heights, the fiord-like lake extends 32 miles. The grandeur of the scenery readily lends itself to superlative description, but exact statement must be moderate. The walls of the canyon are sloping, not precipitous. Bare and gray and desolate, the mountain sides and cloud-draped peaks are very impressive, but though their height be 6,000 feet above the lake they nowhere tower in precipices like Yosemite walls. The maximum inclination is usually near the water surface, and for a hundred feet or so may locally approach 60 degrees. Generally it is less than 40 degrees. And from this steepest facet the profiles rise in a curve which is convex upward, and pass into the nearly level spurs of the adjacent ranges. The narrowest and boldest section of the canyon is just above Safety

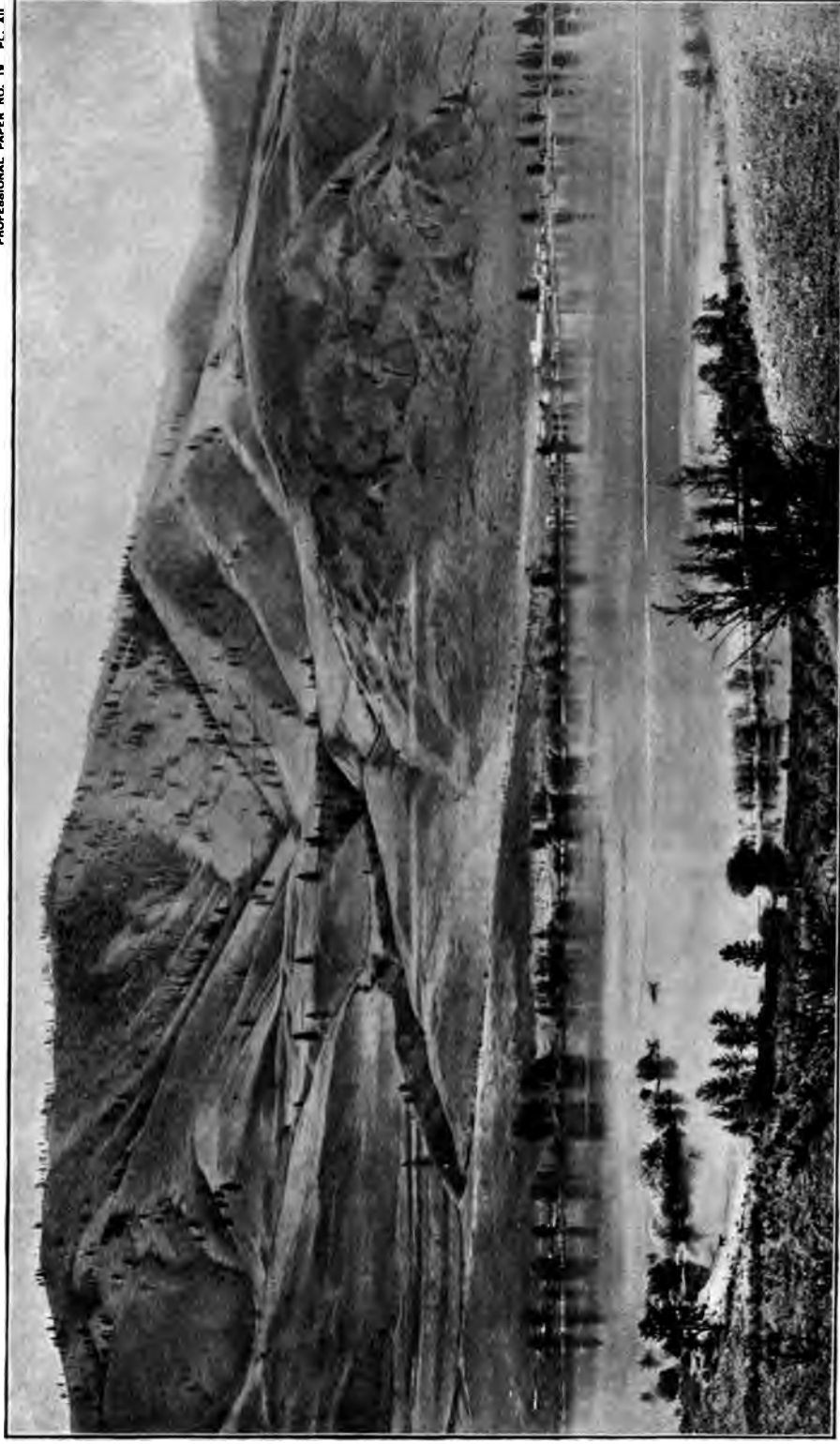
Harbor Creek. It is called the Narrows and is shown in the view Pl. XIII, and in profile in fig. 5 of Pl. XIX.

The physiographic features of the fiord lake are readily correlated with those of the Columbia River gorge. The steeps of the latter are not only homologous with the walls of the former, but they are mutually traceable one into the other through Navarre Coulee, Knapp Coulee, and the Lower Chelan Basin. That they are due to a common activity—the familiar corradng action of a stream—is apparent. They differ, however, in certain aspects. The gorge of the Columbia exhibits acute pin-nacled rock ledges cropping through slopes of soil and loose rock. The canyon of Lake Chelan presents massive rounded bosses of rock, cleaned and worn down by a mighty scouring action. This is the work of ice which, as a glacier, flowed through the fiord, driven by the accumulations in the tributary valleys of the Cascade Range.

The diverse aspects of the Chelan Basin invite discussion. Its lower valley section and its upper fiord-like extent are of different topographic stages, the one being mature, the other young. Their diversity may be explained as the result of either one of two conditions or of their combination. The lake basin below Twentyfive Mile Creek may be cut in softer rocks than the part above that stream, and its more advanced topographic development may be due only to a consequently greater rate of erosion. Or the section below Twentyfive Mile may actually date farther back in time than the upper portion, and may have attained its present stage through longer exposure only. But in the view now held by the writer both of these conditions have been effective.

As to the rocks in large masses they may be considered in two classes. The softer ones are gneiss and schist; the harder are jointed intrusive rocks. Granite occurring as dikes outcrops in bold ledges in Chelan Butte and elsewhere, and is one occasion of the high divide south of eastern Chelan Basin. Rhyolite-porphyry and granite-porphyry dikes stand out ruggedly as the crest of the Chelan Range, and similar rocks occur extensively in the Methow Range, at least about the head of Safety Harbor Creek. On the other hand, the rocks seen north of the eastern part of Lake Chelan are micaceous and schistose. In so far as these differences coincide with heights and hollows, we may attribute a certain effect to them, and the most conspicuous instance of such coincidence is found about Lake Chelan below Twentyfive Mile. But on the whole the region is characterized by indifference of topographic phase to rock structure, and the distinctions described are not adequate in themselves to explain the great features of Lake Chelan.

A number of facts go to show that the Stehekin-Chelan canyon is a composite one, and that the development began at the east and extended westward. In that case the eastern section dates farther back, and its advanced topographic aspects



CHELAN BUTTE FROM NORTH SHORE OF LAKE CHELAN.



may thus be explained as not only more aged in appearance, but actually older. If the valleys of Navarre and Knapp have been properly interpreted as beheaded, Chelan Canyon, below Twentyfive Mile, carries their headwaters. The drainage once consisted of Chelan Brook, a little stream which entered the Columbia at the old outlet of the Chelan Basin half a mile above its present mouth, and which headed east of Knapp Coulee; of Knapp Creek which drained certain slopes north of the present Lake Chelan; and of Navarre stream, which was composed of First Creek, Twentyfive Mile, and the brooks that enter Lake Chelan east of Falls Creek. It is doubtful whether Falls Creek then existed, and a divide is thought to have extended from Navarre peaks of the Methow Mountains uninterruptedly across to the Chelan Range. According to hypothesis, little Chelan beheaded Knapp, greater Chelan captured upper Navarre, and the valley below Twentyfive Mile was established in its present course.

This piracy is attributable in part to adjustments of drainage to hard and soft rocks. As already stated, both Navarre and Knapp coulees exhibit sharply accented canyons near their northern ends. These are in hard granite. Columbia River, if it encountered this same granite axis farther east, would reduce the obstacle much more rapidly than the smaller streams could, and thus little Chelan Brook, flowing on softer gneiss with a low outlet might gain sufficient advantage to divert its stronger neighbors. It is believed that this condition existed and was influential in effecting the readjustment, but its sufficiency is doubted unless it was aided by other circumstances.

Deformation is believed to have played an important if not a major part in the diversion of upper Navarre and Knapp to Chelan. As will appear in the synthetic study of the Methow plain, its remnants are recognized south of the ridge which connects Baldy Mountain and Chelan Butte and on the western part, but not on its eastern extension. (See Pl. XVII.) The area of the ridge appears to have suffered greater degradation, which is attributed to that greater elevation of which there is evidence in the position of the Methow plain. This upwarp stretched across the courses of Navarre and Knapp streams and ponding their upper courses, made them an easier prey to little Chelan. The accented canyons which they now exhibit as the upper sections of the coulees are interpreted as evidence of the efforts made by the streams to maintain themselves before capture.

The preceding interpretation suffices only for the Lower Chelan region. The extension of Chelan drainage above Twentyfive Mile and to the Stehekin is still to be explained, and that explanation depends chiefly upon the slope, which connected the upraised surface of the Methow plain at an altitude of 8,500 feet or more with the level of that same topographic surface east of the Columbia at 3,500 feet. This slope is shown in fig. 4, Pl. XIX, east of Navarre Peaks, but it is there probably

gentler than it was toward the basin of lower Lake Chelan at the place where Chelan drainage headed against it. There can be no question but that the development of that slope caused vigorous growth of the head branches of streams rising on it, and that capture and diversion of any river less favorably situated must result. That there was such a river appears to follow from the recognition of an old valley which now lies at a great elevation and is completely dissected. In describing this feature it will be convenient to name it, and it will be called Russell River.^a

The valley of Russell River was first recognized in the summer of 1899 in a view east and northeast across the Entiat and Chelan mountains. On the southeast the Mount Stuart group formed the right wing, and on the northwest the high summits of the Cascades were the left wing. In the far distance on the horizon lay the basalt plateau of central Washington. According to expectation, the Chelan and Entiat mountains, extending from the high Cascades on the west to the basalt plateau, should descend in a general slope without marked depression along the mid-sections, or decided elevation in the eastern ends. But such depression and elevations were striking features of the view. Stormy (7,219 feet), Baldy (6,432 feet), Tyee (6,688 feet), and heights in the eastern Entiat mountains not yet mapped stand higher than those portions of the ranges between them and the Cascades. The profiles of the lower mid-sections of the ranges are peculiarly flat and suggested cross sections of a shallow valley. The heights east of the mid-sections are traversed by the deep canyons of Entiat River and Chelan, such canyons as should be formed by streams attacking an elevated bench and retrogressively cutting into it. The slope of the supposed bench forms the eastern side of the Cascade mass and is a necessary feature connecting the mountain block with the lower surfaces on the east. And a stream flowing on the bench and parallel to its face in the general position of a valley corresponding with the lower mid-sections of the range would be peculiarly liable to capture.

When in 1899 this hypothesis of the former existence and complete diversion of Russell River was framed, equal consideration was given to another explanation. It was that the depression along the mid-sections of the ranges was due to a zone of weak rocks, which had wasted faster and yielded lower divides between the attacking streams. In 1900 these hypotheses were tested so far as practicable. The depression was clearly recognized from various points of view on the Chelan and Methow mountains, and it was visited at the only place accessible to the route followed. This place is in the southwest corner of the Methow quadrangle (see Pl. XVII), about the head of Lake Creek. The divide between Lake Creek and Lake Chelan is 5,900 to 6,000 feet above sea, and the heights on the east rise above 6,700 with points over 7,000, while those on the west reach 8,500 feet at a considerable distance. The low

^a In honor of Prof. I. C. Russell, who first published an account of the Methow plain, on which the river flowed



NARROWS OF LAKE CHELAN.



pass is a mile and three-quarters wide between the points of the 6,000-foot contour. The ridge was examined for the presence of a weak zone of rocks, but it was found to consist of gneiss cut by granite in essentially the same relations and of the same general character as the masses of the heights on either side. Specially active work of the streams opposed to each other across the divide is not evident, the crest being broad and deeply covered with soil. The further thought that the depression was due to locally energetic agencies of present streams or possibly of past glaciers, was therefore not sustained.

On the other hand, positive evidence of Russell River, such as river gravel, was not found, and indeed could hardly be expected to have survived. The ancient stream thus remains in a measure hypothetical rather than known, but its supposed course may be sketched as follows: The headwaters of Russell River are now known as the Stehekin and are diverted to the Chelan system, the diversion having occurred at a point now about 10 miles southwest of Navarre Peaks (Pls. VIII and XVIII), and 6,100 to 6,300 feet above sea; that is in the air 5,000 feet or more above Lake Chelan. Thence the course of Russell River was across the divide at the head of Lake Creek, the valley floor lying probably above the lowest sections of the ridge as it is now sculptured. Lake Creek may be a surviving remnant of the old stream, representing a beheaded section which was cut off also from its lower course by the Entiat. Between Entiat and Wenatchee rivers the valley of Russell River is marked in the heights, and the course was probably southwesterly. Finally Russell River joined the Wenatchee, of which it was the northern and possibly the principal branch.

Reverting now to the development of the Chelan system, we have to consider what may have been the conditions if Russell River did not exist. In this case the writer has little to present that is satisfactory. It may be assumed that Chelan and Stehekin constitute a consequent stream, which has flowed in its present course without any such complex adjustments as have been discussed; but in that case the beheaded condition of Navarre and Knapp coulees remains an unsolved and apparently insolvable problem. If again it be suggested that Navarre stream formerly included not only Twentyfive Mile but also all the upper Chelan-Stehekin drainage, the valley of Navarre is disproportionately small, and the diversion of so large a river to the present outlet appears altogether improbable.

The youthful aspect of Chelan Canyon above Twentyfive Mile remains a fact, whatever the early history of the drainage system, and is due to and evidence of recent uplift of the mass in which it is sculptured. Its significance in relation to deformation will be further considered in discussing that subject.

ENTIAT MOUNTAINS.

To see the Entiat Mountains against the sky and in their relation to the Columbia gorge and Badger Mountain, one should ascend the spur between Navarre and Knapp coulees to an altitude of 3,100 feet. Thence Badger Mountain presents an unbroken even-topped height which is taken up by the Entiat Mountains and carried westward for 2 miles till it rises into conical peaks 800 feet higher. (See profile 7, Pl. XIX.) The otherwise uniform sweep is broken by the great valley of the Columbia, which clearly exhibits its inner gorge and outer slopes. Restoring what the river has cut away, the topographic continuity of Badger and Entiat is apparent, and they are also geologically a unit, since the basalt and gneisses occur in similar relations in both.

The continuity of structure and profile of the mountains which the Columbia divides shows that they are of one mass that moved as a unit in the uplift of the region. Similar reasoning and conclusion apply to Waterville plateau and the mesa north of Entiat River. They also, though divided, are of one mass, but their surfaces lie 1,000 to 2,000 feet lower than the mountains. The river's trench is deeply cut in both masses, but if we filled it to the brink between the plateau and the mesa, the stream could not flow across the higher mountains before it. It is clear that when the river adopted its course the mountains were not higher than the plateau, but that since that time the Badger-Entiat mass has been raised higher than the region north of it. As has already been pointed out, this uplift sufficed to cause the diversion of the lower part of Entiat River, but it did not rise with sufficient rapidity to turn the great master stream, the Columbia.

The broad flat at the eastern end of the Entiat Range, 4,500 to 4,900 feet above sea, corresponds in extent with a basalt remnant. The dip of the basalt is not less than 3 degrees and probably nearer 5 degrees to the north. The slope of the surface is about $1\frac{1}{2}$ degrees in the same direction. The dip and slope therefore appear to diverge 150 feet or more to the mile. If we assume that at any time the surface was level, the basalt then dipped $1\frac{1}{2}$ or more degrees, and the level crossed the basalt beds at a slight angle. It is more probable that the surface declined slightly down the course of the Columbia and was cut across the nearly level basalt. Both have been tilted in the uplift of the Entiat Range.

Though small, the angle at which the flat surface and the basalt bedding diverge is important, since the surface is thereby identified as one of erosion in contradistinction to one of structure. The evidence is slight and by itself insufficient to establish a conclusion, but it is sustained by the fact that in this region similar flats are cut across structurally indifferent gneiss and granite, and it is corroborated in the Yakima district by the definite observations of G. O. Smith, with which it is in line.



VIEW FROM CHELAN BUTTE. LOOKING SOUTHWEST DOWN THE COLUMBIA VALLEY.



CHELAN MOUNTAINS.

From Columbia River at Navarre Coulee an Indian trail leads to Stormy Mountain, the highest point of the Chelan Range, and following the crest for some miles in a northwesterly direction crosses the Entiat Valley and the Wenatchee Mountains toward Leavenworth. Like most Indian routes in this region, it was chosen from among the many possible ones because it presented little difficulty to the passage of horses, the ridges followed being of gentle rise. To this fact of topographic form and to exceptions to it, attention is now called.

After a sharp scramble of 1,200 to 1,600 feet it is a surprise to ride out upon nearly level or broadly rounded surfaces which are deeply mantled with soil. Yellow pines (*Pinus ponderosa*) grow vigorously, but widely spaced, as is their habit; the surface is scantily covered with grass, and groups of shrubs stand here and there. A few hundred feet to right and left this surface rounds off into steep slopes that descend to adjacent hollows. Follow a lateral spur of the ridge and you come to a cliff, the margin of a larger ravine. Pursue your course northward along the ridge and you ascend easily, though with occasional slight descent, to about 4,000 feet above sea. Gradually the ascent becomes steeper to the top of a ridge at 5,000 feet, and following this two miles to the eastern side of Baldy Mountain you strike a moderate slope of limited extent at about 5,500 feet above sea. Above this Baldy presents a serrate ridge whose highest tooth attains 6,432 feet above sea. The height, the ragged angular forms, and bare talus all mark the hardness of the rocks, rhyolitic porphyry and granite, which occur in a system of large dikes traversing hornblende-gneiss. Stormy Mountain (7,219 feet), the spur (7,142 feet) 8 miles northwest of Baldy, and much of the intervening crest are sustained by similar dikes and present the same acute topographic forms, but adjacent to them, at elevations above 6,000 feet, there are gently rounded flattish surfaces, which are physiographically not in sympathy with the active work of frost on the peaks above or the energetic corrasion progressing in the ravines near by. These flats are of small extent, but of definite character. The most apparent one lies between Twentyfive Mile and Lake creeks, where the divide trends north, leaving the dike system of rhyolitic porphyry that runs out in the sharp peak at 7,142 feet. For convenience, it may be called Fourmile Ridge. The prevailing rocks of Fourmile Ridge are granite and gneiss, which afford no structural occasion for the flattish surface. For a distance of 4 miles the summit has a general elevation above 6,600 and below 6,800 feet, declining gently northward. It is slightly notched at several points, and even where it widens out it is rounded, not level. But lying as it does between steep and even precipitous slopes which descend a thousand feet into the adjacent depths, its grassy, soil-covered surface is a striking remnant of an earlier physiographic

condition. It is a derivative from a plain, and although modified it has not lost its significant aspect, a long and practically continuous uniform slope. (See profile 5, Pl. XIX.)

Had the rider, ascending from the Columbia along the old Indian trail, turned southwest on the level above the 3,000-foot contour, he might have followed the divide between the Columbia and the Entiat, over the broad hill having an altitude of 3,757 feet, and out onto the bit of plateau or mesa which overlooks the junction of the two rivers. As may be seen from the topographic map, the accents of the ridge are slight, but the ravines carved in its sides are acute. The surface at an altitude of about 3,757 feet, its northeastern and southwestern spurs, and the mesa southeast of Strummel Canyon are peculiarly broad and simple forms as compared with their environment. The mesa exhibits occasional basalt scarps and is a corner of the Waterville plateau isolated by the Columbia Gorge. Through its structural and physiographic characters it is an important link between the great plateau and the Chelan Mountains. Approaching the mesa in form, but unlike it in rock structure, the hill having an altitude of 3,757 feet continues the same topographic phase, and its spurs extend the type on the one side to the Entiat Gorge, on the other to Navarre Coulee.

Considered as a whole, these features are clearly distinguishable from the steeps which are now subject to energetic corrasion by brooks and rivulets. Considered in detail, two less clearly distinct phases may be recognized among these broader features. Discriminating by form we may find surfaces which approach a plain and those which are marked by moderate relief; judging by relative elevation, we shall discover the plainer surfaces above the more clearly sculptured ones, but without definite boundaries between them. Carrying the comparisons over wider areas the flats are found at different heights, but always in the same physiographic relations.

Thus, physiographically, the mesa, the spurs of the hill with an altitude of 3,757 feet, and Fourmile Ridge belong to one and the same stage. The crests of the hill which has an altitude of 3,757 feet, of Baldy, of Stormy, and of the hill which has an altitude of 7,142 feet, are older monadnocks, whereas the long spurs of the range fall into the class of later features, and the canyons of all magnitudes into that of the latest.

METHOW MOUNTAINS.

The Methow Mountains lie between Lake Chelan on the southwest and Twisp and Methow rivers on the northeast. Only their southeastern portion, up to Stai Peak, is included in the accompanying map (Pl. XVIII) and in the profile (Pl. XIX). A portion of it, known as Sawtooth Ridge, extends with serrate and glacier-bearing peaks into the heart of the high Cascades.



VIEW FROM CHELAN BUTTE, LOOKING NORTHWEST OVER LOWER LAKE CHELAN TO STORMY MOUNTAIN AND NAVARRE PEAKS.

At their eastern end the Methow Mountains are no higher than the neighboring plateau east of the Columbia. Like the Entiat and Chelan mountains they are structurally continuous with the plateau, from which they are separated only by the canyon which the river has cut. Looking northward from Chelan Butte or the margin of the plateau above Chelan Ferry, the sky line of the plateau is continuous with that of the Methow Mountains at an altitude of about 3,400 feet. Rising westward with moderate grade the peaks of Navarre are reached, 7,800 to 8,200 feet above sea, and thence northwestward for many miles the summits are of remarkably uniform altitude.

As a mountain mass between Lake Chelan and the parallel valleys northwest of it, the Methow Mountains are 12 to 15 miles across from southwest to northeast. They have a very definite watershed from which all streams flow by the shortest routes to Chelan, Twisp, or Methow rivers. West of a line drawn north and south about 3 miles east of Navarre Peaks the crest is narrow and often ragged, but high spurs extend out on either side to distances of 3 or 4 miles, maintaining in their heights the general altitude of the watershed. Navarre Peaks are the southeastern representatives of a large number of points which closely approach or slightly exceed 8,000 feet in elevation, and which are linked together by high ridges branching from and on a general level with the central divide. These peaks and spurs are clearly derivatives from a plateau.

The eastern part of the summit exhibits some broad areas, and from them the spurs decline gradually, especially toward the southwest. As compared with the deep canyons cut in them, these surfaces belong to an earlier stage of topographic development. They are residuals which distinguish the district east of an ideal line from the region of acutely mature topography west of it. The distribution of these residuals and of the drainage lines flowing southwest and northeast suggests that the surface between the Methow and the Chelan east of Navarre Peaks would, if restored, form an arch pitching southeast and merging in that direction into the basalt plateau. Traced westward this arch flattens out in a level above the summits of the higher part of the range.

In topographic forms and drainage the Methow Mountains present most interesting problems which involve the discussion of earlier topographic phases, deformation, stream adjustment, and glaciation. But the writer's opportunities for observation have not been sufficient to solve them.

SYNTHETIC DISCUSSION.

GENERAL STATEMENT.

In the preceding pages the separate features of the region have been described as they now are, and their interpretation in terms of topographic development has been suggested. In what follows it is proposed to discuss each stage of that development from the earliest recognized up to the latest glacial epoch. The glacial phenomena are very conspicuous and have been noted from the terraces of the Columbia to the lingering glaciers of the Cascades, but their record is one which is more complex than can be read without special studies which are yet to be made by an experienced glacialist. That chapter is therefore not included in this discussion.

Enough has been said in the descriptions to indicate that several stages of topographic development have been recognized. They are clearly evident in such a profile as No. 1, Pl. XIX, from the Entiat Mountains across Columbia Canyon to Badger Mountain. Beginning with the highest, the peaks (5,700 to 5,800 feet) and the flat adjacent to them are considered to be representatives of the oldest stage of which definite evidence remains. They are correlated with Badger Mountain, the Waterville plateau, surfaces in the Chelan and possibly the Methow Mountains, and the level from which the high Cascades are sculptured. This oldest stage is therefore that of the Cascade plateau, as named by Russell, but now called the Methow stage. It is also identified by G. O. Smith. The characteristic topographic type of the Methow stage was a plain, upon which residual hills survived. Following Davis, it may be designated a peneplain, with monadnocks.

Within this plain were carved valleys which appear to have attained nearly mature development. That of the Columbia in profile No. 1, Pl. XIX, appears to have been 2,000 or 2,500 feet deep and 7 or 8 miles wide. The smaller streams certainly developed shallower and narrower valleys, but remnants of the Methow plain west of the Columbia were few and limited. On account of its preservation in the basin of the Entiat, this stage is named from that river. The characteristic topographic form of the Entiat stage is mature. It occurs as a spur or divide below occasional residuals of the Methow stage and above features of later stages.

Within the relief of the Entiat stage there were cut deeper channels, some of them canyons of impressive depth, many of them simply mountain ravines. They constitute the most marked and everywhere the most characteristic features of the topography of the region. Any large stream might be chosen as exhibiting the type, but probably none shows it in various degrees better than the Twisp, which from its junction with the Methow to its source in the Cascades lies in a canyon that varies from a few hundred to 4,000 feet in depth, as can be seen on the Methow topographic

atlas sheet. This stage is accordingly named Twisp. The characteristic of the Twisp stage is a canyon, the typical feature of topographic youth, but the development progressed far toward maturity.

The Twisp stage closed with accumulations of glacial ice, which occupied the canyons and in many instances greatly modified them. Rivers overloaded with drift filled their channels to greater or less extent. Lake Chelan and the terraces of the Columbia near its outlet afford the most conspicuous examples of these phases of activity. This stage of glaciation will accordingly be called the Chelan stage.

With retreat of the glaciers to the highest amphitheaters of the mountains the streams began to reexcavate their channels. The glaciers still linger and the rivers are still engaged in removing drift. To complete the sequence of stages, this latest and present one may be designated from a stream which flows from several surviving glaciers and is clearing its old valley of drift, the Stehekin.

It is somewhat difficult to place these several stages in geologic time. On the evidence of fossil plants from the Ellensburg formation, the Methow plain in the Yakima district is post-Miocene. The data are fully presented by G. O. Smith, and the unity of the feature throughout the Cascade Range is discussed by the writer under its proper head below. The very long time required to accomplish such extensive and uniform leveling appears reasonably to occupy most of the Pliocene and to bring the date of the next stage near the close of that epoch.

The line between the Pliocene and Pleistocene can not be fixed with certainty. By definition Pleistocene begins with and dates from the earliest Glacial epoch. In the Puget Sound Basin there are deposits of two glacial advances with those of an inter-Glacial epoch, but in the region of glacial erosion and on the eastern side of the Cascades generally the observed record is of one advance only. The relation of the repeated record to the simpler one has not been made out. They may correspond to the same time interval, during which in the lowlands of Puget Sound there was an epoch of glacial retreat not marked in the mountains. In that case glaciation of the canyons covers the whole time of glaciation and all glaciation was later than that of canyon cutting. In other words, the Twisp stage was pre-Glacial, and therefore pre-Pleistocene. On the other hand, it is equally probable that glaciation of the heights as now recognized corresponded only to the later epoch which is recorded in the Vashon till of Puget Sound. An earlier epoch of glaciation, that of the Admiralty till, in that case occurred also in the Cascades, but has not been made out. Its record may not be recognizable if the Twisp stage of energetic erosion corresponded with the inter-Glacial episode. On that hypothesis, the Entiat stage may have been early Pleistocene.

The following tabulation expresses the most reasonable estimates of correlation for the several stages in geologic time.

Physiographic development of the Cascade Range.

Physio-graphic stage.	Type locality.	Nature of characteristic activity.	Date, if one un-interrupted Glacial epoch.	Date, if two or more Glacial epochs.	Period.
Stehekin	Stehekin sources and valley.	Glacial retreat and reexcavation of old valleys.	Post-Glacial to present.	Post-Glacial to present.	Recent.
Chelan	Gorge of Lake Chelan and terraces of the Columbia.	Glacial occupation of canyons, canyon modification, and valley filling by overloaded streams. Glacial diversion of streams.	Glacial epoch ..	Latest Glacial epoch.	Pleistocene.
Twisp	Canyon of the Twisp, Methow quadrangle.	General acceleration of corrosion, resulting in excavation of canyons and ravines with readjustments of drainage.	Pre-Glacial	Inter-Glacial ...	Pliocene or Pleistocene. (Sierran Age.)
Entiat	Basin of the Entiat and foot spurs of the Chelan Range.	Development of mature topography generally throughout the Cascade plateau.	Pre-Glacial	Earlier Glacial epoch.	
Methow	Generally throughout the broad mountain district, and specifically in Yakima Valley.	Planation by erosion to a low plain with monadnocks.	Pre-Glacial	Pre-Glacial	Pliocene.

METHOW STAGE.

CONDITIONS OF DEVELOPMENT.

The characteristic feature of the Methow stage was a plain, and where now recognized the essential form of the remnants is a flat, or approaches a flat, from which the existing surface is immediately derived. The plain might have originated through (a) marine deposition, (b) marine planation, (c) as the original surface of a lava flow, (d) by erosion to a peneplain.

(a and b) Marine deposition and planation are excluded from among the possible conditions of development of the Methow plain, because the surface extended over hundreds of square miles without being in any way conformably related to any sedimentary formation, and is cut unconformably across the bedding of the youngest sediments of the district, the Ellensburg formation.

(c) The original surfaces of Miocene basalt flows probably coincide with the Methow plain in some areas of the Columbia Basin, and it has been thought that these coincidences were so extensive that the plain was determined by the basalt, at least as far as the flows extended. The writer's local observations about Waterville and west of the Columbia are not satisfactorily definite in this regard. At the one point where dip of the basalt could be seen in the Entiat Mountains there is a slight unconformity, but generally no good observation was possible. In the Yakima district, however, where the evidence of coincidence was thought to be most striking, G. O. Smith has observed a general unconformity, which, though commonly slight,

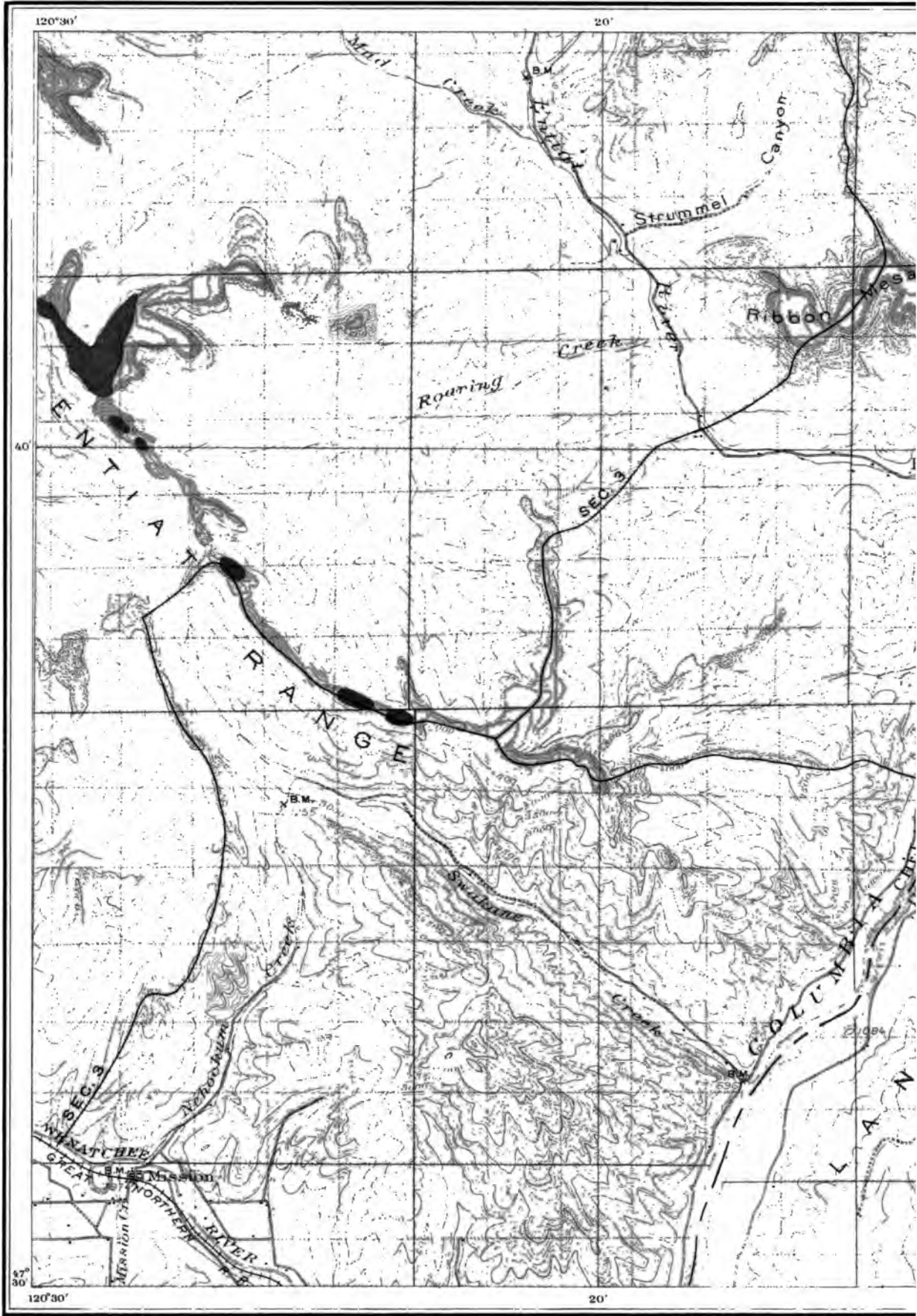
Relative elevation is an important factor in recognizing remnants of the Methow plain, but in this respect elevation above sea is less significant than position above other features. Since in course of physiographic development an older residual feature commonly lies above all younger forms, we should look for remnants of the plain, the oldest surviving phase, at the greatest altitudes in any locality; but where the plain falls below any summit we are constrained to recognize the latter as a residual, or monadnock, upon the plain.

Distribution and character of residuals.—Detailed geologic surveying with adequate base maps has been carried out in the Cascade province chiefly by G. O. Smith. His identification of the Methow plain in the Yakima province is described by him in the earlier part of this paper, to which the reader is referred. In what follows the plain is traced in the district between Wenatchee and Methow and in portions of the high Cascades seen by the writer.

The distribution of recognized residuals is shown on the maps, Pls. XVI, XVII, and XVIII. The mapping is an adaptation of observation to base map, carried out in the office and largely guided by the topographer's delineation of forms. Exact boundaries can not be recognized in the field, except occasionally for short spaces, and none are attempted in the graphic statement. The areas delineated as representing the Methow plain are not thought ever to correspond exactly in surface with it. They have been modified slightly by corrasion and materially by disintegration and wind erosion; but they retain the typical character of the plain sufficiently to demonstrate its former existence and to represent it.

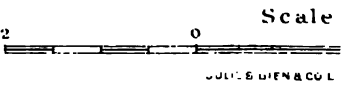
In the Waterville plateau wide areas are characterized by flatness. They occupy the positions of broad divides and are commonly distinguished from lower, gently sloping surfaces by an intermediate steeper facet. They are unsympathetic to the slightly accented drainage channels, and they fall into one general plain. They probably correspond nearly with the surface of basalt flows, but no outcrops of the rock were observed, deep soil prevailing everywhere within sight of the writer's route except on the scarps toward Columbia River. Their great extent removes them from the category of surfaces possibly due to rock structure only, and their other characters identify them as residuals of an ancient lowland plain of erosion.

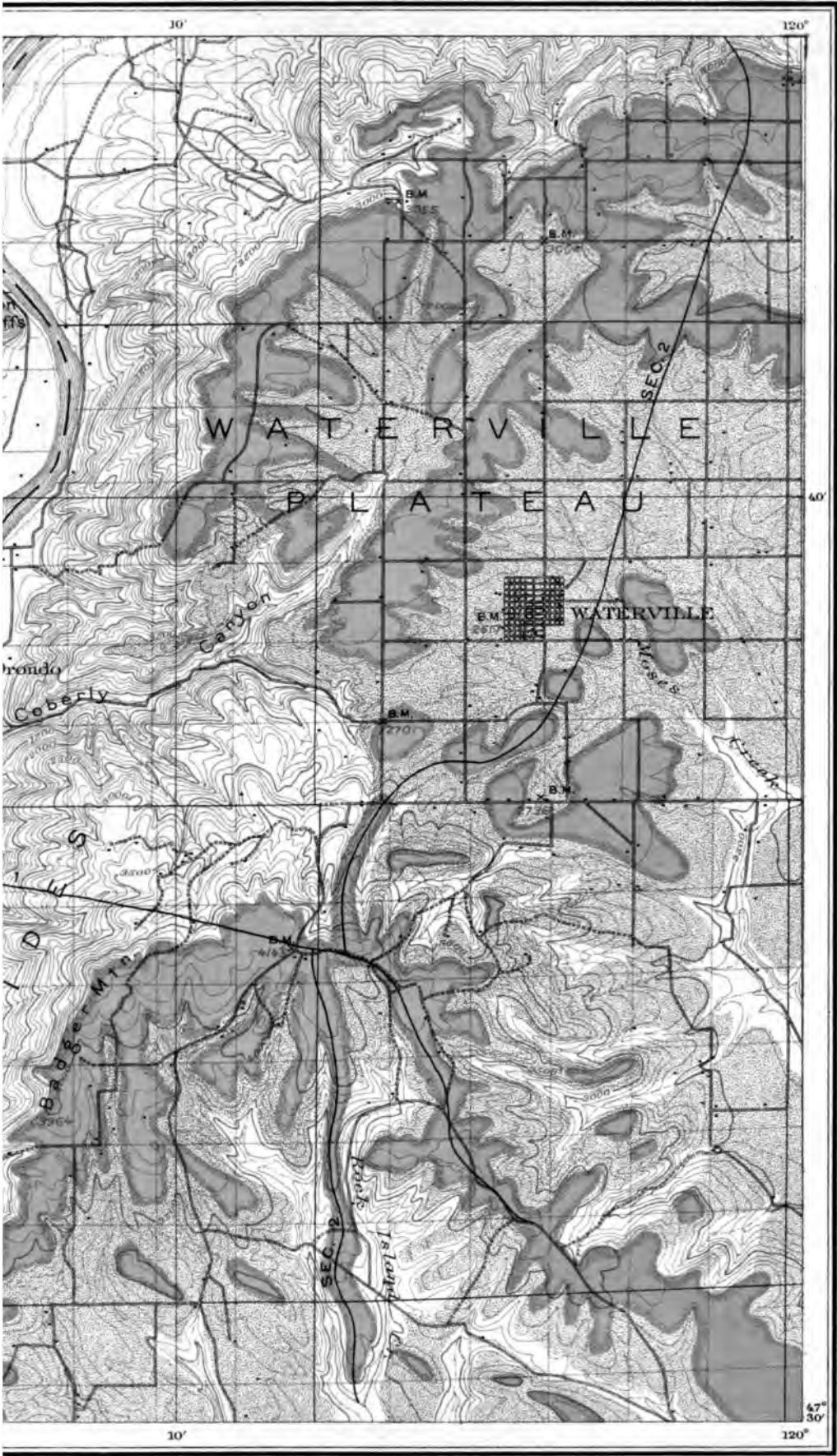
Two isolated hills southeast of Waterville and the nearby spurs of Badger Mountain are believed closely to approach the flat of the Methow plain. The spur east of the main road from Waterville across the mountain most nearly continues to the summit an unbroken surface, which may be considered representative. The top of Badger Mountain has the character of the Waterville plateau, and long, even spurs extend this aspect into the valley of Rock Island Creek on the south. Independent physiographic evidence of Columbia Canyon and some meager structural facts show that the mountain is an anticline of later development than the



R.U. Goode, Geographer in charge
Triangulation by W. T. Griswold
Topography by R.A. Farmer and W.T. Griswold
Surveyed in 1897-98

PHYSIOGRAPHIC MAP OF THE SOUTHERN
INCLUDING PART OF THE COLUMBIA PLATEAU
THE EASTERN SPURS OF THE





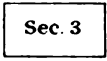
LEGEND


Monadnocks on the
Methow plain


Areas which in form
and altitude accord
nearly with the Methow
plain


Areas which in form
and altitude accord
nearly with features
of the Entiat stage


Areas which exhibit
features of the Twisp
and later stages


Sec. 3
Numbers refer to
sections on PLXIX

OF THE CHELAN QUADRANGLE
THE COLUMBIA CANYON, AND
SCADE RANGE

Physiography by
Bailey Willis, Geologist

4 miles

Methow plain, which should accordingly rise above the arch or to a greater or less degree coincide with it. In general profile the coincidence appears to be close; the summit and southern slopes are probably not much modified; but the northern slope is dissected until very little, if any, part of the surface represents the plain.

South of Rock Island Creek the characteristic broad expanses extend to the escarpment above the Columbia gorge and their sky lines are continuous across the canyon with the heights of Table Mountain, from which they descend to the Yakima Valley.

The Methow plain west of the Columbia is preserved in a few small remnants only. The even slope on basalt in the eastern end of the Entiat Mountains, 4,800 to 4,900 feet above sea; Ribbon Mesa, 3,300 feet; spurs above the contour of 3,400 feet on the hill, which reaches an elevation of 3,747 feet; and Fourmile Ridge, 6,700 feet, have all been described. They are topographic flats which are on the whole not determined by structure planes of the basalt, where there is basalt, and which occur on jointed and schistose rocks as well, which are not in sympathy with their present environment, and which have, to later topographic stages, the relation that the Cascade plain holds. Therefore, in spite of their considerable and diverse altitudes, they are identified as residuals of that once continuous lowland.

It is possible that detailed study of the Chelan Mountains between Baldy Mountain, Ribbon Mesa, and Chelan Butte will discover other bits of the plain on summits of spurs and about monadnocks. There is room for question whether the hill which rises to an elevation of 3,757 feet is a monadnock or not. The plain may sweep above it, but the general interpretation of facts would not be modified in any essential particular by such changes in the determination of local positions.

Of the Methow Mountains the writer has not seen the portion east of Navarre Peaks except in general views from a distance. Their profile thus seen is characteristically that of a tilted, somewhat dissected plain. They rise with continuous line from the plateau level east of the Columbia from 3,400 feet or less to 6,000 feet above sea. They then appear to sweep up in a steeper but moderate grade to the heights of Navarre Peaks at 7,800 feet. The topographic map and the profile derived from it (fig. 4, Pl. XIX) confirm this observation. Along the crest, from 3,400 to 6,000 feet above sea, there are residual surfaces of flat form unsympathetic to their environment. One extends from 3,600 feet to 3,800 feet. There is then a rise over Cooper Mountain, which is probably a monadnock, about 300 feet above the plain. Beyond this the flats occur near or above 5,600 feet, with ascent to 6,100 feet, and thence upward the crest is sharp. Navarre Peaks might be regarded as summits older or younger than the flat surfaces—as

monadnocks or descendants;" but, considered in their relations to the many heights of about the same altitude which occur west of them and connect them with the general level of the high Cascades, Navarre Peaks appear to be descendants, and the plain sweeps up to and over them.

The reconstruction of the Methow plain has proceeded thus far upon identification of residuals, which actually or so nearly represent its surface that they may be taken for it. In extending the reconstruction further over the Methow Mountains and the high Cascades, another line of reasoning must be followed.

In the Cascade Range views from high altitudes present two striking features, that mutually are in strong contrast. The one is the acuteness of the mountain forms, often sharply needle-like; the other is the uniformity of general elevation which these boldly sculptured peaks approach. The sharp forms result from the activity of frost and thaw, of corrasion, and of transportation in shattering and removing rock masses, whose principal controlling structure is steep jointing. The uniformity of heights has been interpreted as inheritance from a former plain surface, and also an effect of erosion at great altitude.

The latter hypothesis has been considered in view of facts closely resembling those observed by Dr. Dawson, its author, in the same mountain range, but it does not seem to be sustained. The activities of erosion do not appear to tend toward more uniform effects with greater altitude, on the contrary elevation emphasizes their locally unequal intensities. Corrasion and transportation are effected by falling water, whose energy for a given mass is directly as the fall, and consequently increases with height of land. Corrasion and transportation are very narrowly localized in activity, and hold the same relation to general degradation that a circular saw does to a planer. Their intense application results in deep canyons, the extreme of height and depth. Disintegrating influences, whether chemical or mechanical, may act equally with equal opportunity, but they are controlled by conditions of exposure. Upon an uneven surface these are varied and they become more and more diverse as inequalities of relief develop. The suggestion that frost and thaw may with elevation gain in effectiveness more rapidly than corrasion and so may limit the height to which peaks may attain in a growing range, appears not to be sustained by study of mountains much higher than the Cascades, nor by theoretical reasoning in regard to the work of freezing water. Thus after careful consideration the writer has felt obliged to abandon the hypothesis of development of a common high level among mountain peaks.

The general level of Cascade summits is suggested in the views, Pls. IX and X. The one is the central section of a panorama of three views, looking southwest

"A descendant is a topographic feature carved from the mass beneath an older topographic form which has been removed.

from the head of a tributary of the Yakima across spurs of the range. The other is a view down Stehekin Valley to the distant Methow Mountains. In neither case does the photograph give the full effect of these landscapes; the angle is but 50 degrees of the full circle, of which the greater part may in a central situation show similar effects, and in each of these particular cases the camera was 1,000 feet or more below the peaks, which consequently appear higher near by. To see such a surface of common altitude the eye should be in it. A diagrammatic presentation of the fact of nearly uniform altitudes is given in the profiles of the Methow Mountains west of Navarre Peaks. (Figs. 4 and 5 of Pl. XIX.) Of the dozen or more summits represented in as many miles, none is lower than 7,800 feet and only one, Star Peak, rises to 8,500 feet above sea. While this diagram gives but a single line, several profiles across the range might be constructed showing similar relations of mountain tops on spurs which extend 3 to 4 miles from the central divide.

The fact of uniformity of summit level becomes more and more impressive as it is observed over wider and wider areas. Russell and the writer have found it to extend over practically all of the high Cascades, occurring at altitudes which vary from 6,000 to 8,500 feet according to the portion of the range in view. There will probably be little if any dissent among future observers from the inference that this widespread equality of heights is derived from a landscape of gentle relief, but opinions will differ as to the degree of plainness of the ancient surface. The occurrence of granite monadnocks, such as Mount Stuart, rising a few hundred feet above the probable position of the old plain, is significant in this connection. Were they numerous they would indicate a hilly region, but far apart as they are and of moderate altitude they suggest that planation had made general progress toward a low peneplain.

The present altitude, which the plain would have above the mountain tops if it existed, is yet to be carefully estimated. In that portion of the Methow Range which has been topographically mapped and studied, the summits near and above 8,500 feet (Star Peak, 8,500; Oval Peak, 8,800) have broad, rounded forms. It is possible that they rose to, if not above, the Cascade plain in this vicinity. On the assumption that the altitude of the plain would now be about 8,500 feet, the inherited summits lie 200 to 600 feet below it. This is probably a minimum. On the other hand, if Mount Stuart and similar granite cones are monadnocks, the plain can not well be reconstructed more than 1,200 feet above the ridges which surround them.

ENTIAT STAGE.

PHYSIOGRAPHIC RELATIONS.

The physiographic relations which constitute the chief criteria that serve to identify features of the Entiat stage are those of a development intermediate between an older and a younger stage. In position and in form Entiat residuals lie between the flats of the Methow plain and the canyons of the Twisp stage.

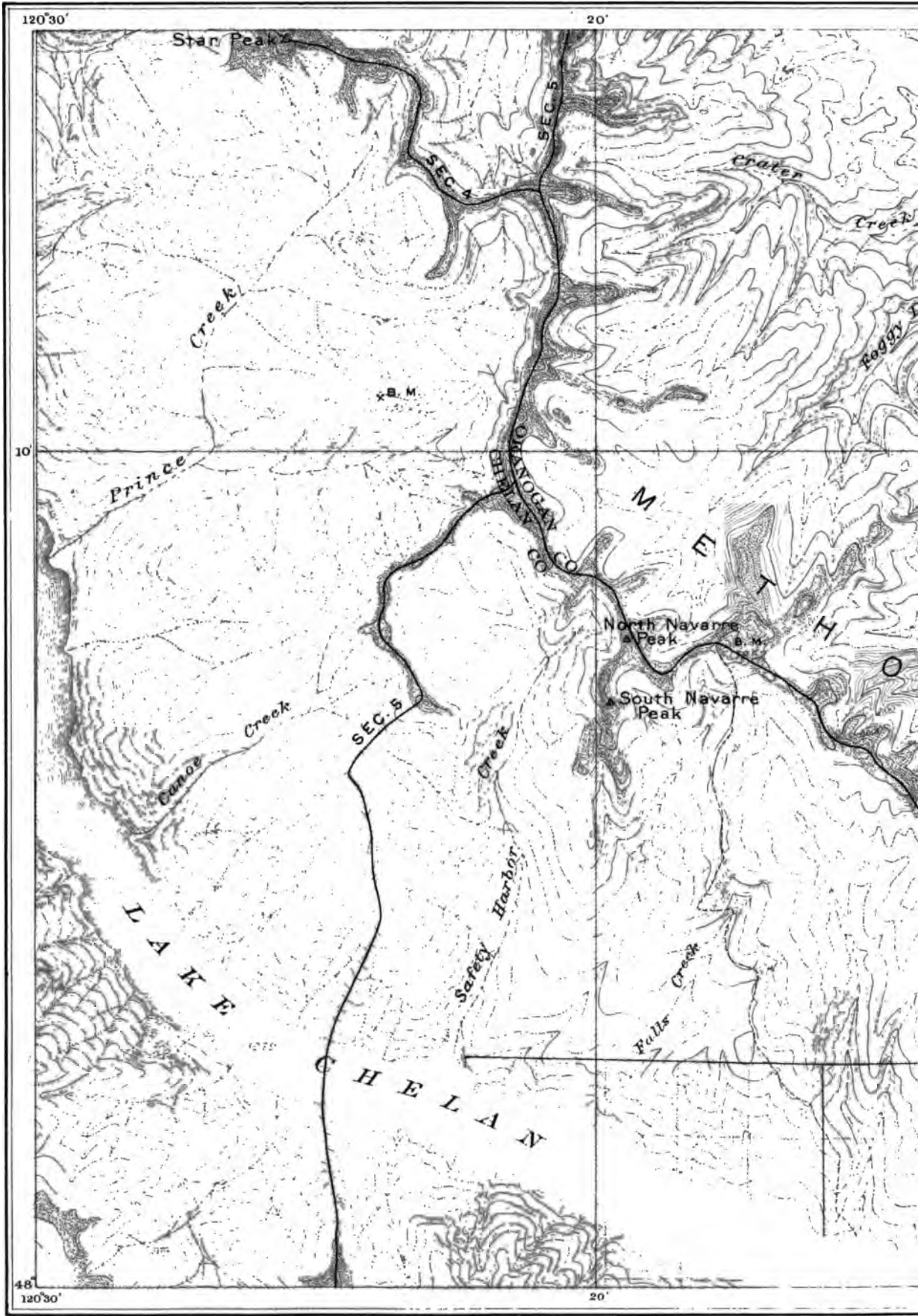
The Entiat stage was first recognized by the writer in riding from Wenatchee up the Columbia gorge and over the high spurs between it and Entiat River. It then became evident that the Columbia Valley consisted of at least two parts, an inner canyon and an outer valley, a younger and an older phase; and above the older were found the surfaces identified as parts of the Methow plain. In extending the observations it was found that a distinction must be made between those parts of the Cascades which had been subject to much precipitation and consequently had suffered deep corrasion, and those which had received slight precipitation and had been but faintly engraved. This difference of sculptures in Entiat time is parallel with the present diverse aspects of corresponding areas of great and little rainfall.

The criteria by which Entiat and Methow features are distinguished have already been stated. Where they both occur adjacently, the former lie below the latter and in unsympathetic relations. The distinguishing point between Entiat and Twisp slopes is a more or less prominent projecting angle or bench. Its significance depends upon the fact that in homogeneous material normal profiles of a continuous cycle are concave upward. The curve or angle which is convex upward or outward may result from rock differences or from glaciation or from revival of stream activity; the first is commonly a local, the others general phenomenon of any particular district. Along the western side of the Columbia the gneiss and granite are unlike in detail, but in general they are homogeneous in their attitude toward erosion agencies. The hills have not been glaciated, nor did glaciers of the latest epoch extend so far down either the Columbia or Entiat. Nevertheless, each of the long spurs of the Entiat and Chelan mountains is characterized by a markedly prominent angle, and in the ravines a corresponding change occurs at the top of a steep stream grade or fall. In all the unglaciated heights west of the Columbia, this angle is a prominent and significant feature. In glaciated slopes the older records cut by the streams are modified by ice work, and the features are more complex.

DISTRIBUTION AND CHARACTER OF RESIDUALS.

Features such as are characteristic of the Entiat stage exist generally throughout the higher Cascades, so far as the writer's observation goes, but residuals, in the sense of unmodified forms, probably do not survive to the same extent as do those of the Methow stage, if at all. This follows from the greater effectiveness of erosion on slopes as compared with that on plains.

Representative Entiat features are rounded or flat ridges, spurs, and gentle slopes, commonly distinguished by a covering of deep soil, as well as by their physiographic relations. To enumerate them would be to repeat much that has been said in describing the ranges, but typical examples may be cited. In the eastern end of the Entiat Mountains the spurs, which extend at about 4,700 feet from the flat of



R.U. Goode, Geographer in charge
Triangulation by A.H. Sylvester
Topography by W.T. Griswold and R.A. Farmer
Surveyed in 1897 and 1899

PHYSIOGRAPHIC MAP OF THE SOUTHERN
INCLUDING MIDDLE LAKE CHEHALIS
AND THE METHOW RIVER

Scale
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MILES

Methow date down to about the contour of 2,600 feet, exhibit typical Entiat profiles. (See profile 1, Pl. XIX.) The ridge isolated by Lake Chelan, Columbia River, and Knapp Coulee is a characteristic Entiat form in its summits and spurs above the 1,500-foot contour. (See profile 2, Pl. XIX.) The rocky height of Chelan Butte is probably a monadnock of pre-Methow date, but the development of Entiat features has gone so far as to remove the plain from about it. The slopes of the ridge are scored by numerous ravines, in which corrasion has progressed steadily during all the time since the Entiat epoch closed. They are therefore more deeply cut than formerly, having steeper grades toward the top. In their lower channels they have been materially modified by deposits of the Chelan glacial epoch.

The profile 3, Pl. XIX, exhibits Entiat slopes in relation to the forms that preceded and followed them. The long spur between Mad Creek and Tyee Mountain, 3,500 feet to 6,500 feet; the spur of the Chelan Mountains, 5,500 feet to 6,700 feet, and those of the Methow Mountains above 6,000 feet, along this section line, are reasonably near Entiat features. They exhibit the long concave curve, the windgaps, and the rounded summits, for the most part deeply soil covered.

There may be features whose age is indeterminate because their aspects and relations are capable of more than one interpretation. Such a one is the flat spur contoured by the 3,000-foot line west of Navarre Coulee and rising by gentle grade to the mountain which has an altitude of 3,757 feet. If of Methow date, it is a part of the plain marked out around the last-mentioned mountain near the 3,500-foot contour, and its inferior position is due to warping. If of Entiat date it is a low level of an early epoch in the widening of Navarre Valley; and in that case, also, it may, in consequence of warping, now occupy a position lower than it had in relation to the Chelan Mountains. Were the ridge continuously broad and gentle of slope from the mountain having an elevation of 3,757 feet nearly to the top of the Chelan Mountains east of Baldy, the former date would seem probable; but the hill crowned by the 3,500-foot contour and several interruptions of the gradual slope by steeper intervals indicate that the plain was eroded, and we have to deal with an Entiat surface which locally developed a flat feature.

DEGREE OF ENTIAT RELIEF.

West of the Columbia the differences of elevation covered by features assigned to the Entiat stage are considerable: In the eastern portion of the Entiat Mountains, from 2,600 feet to 4,700 feet; in Chelan Butte, from 1,600 feet to 3,700 feet; in the district west of Navarre Coulee, from 2,000 to 6,000 feet; in Tyee Mountain, from 3,500 to 6,600 feet; in profile across Lake Chelan from Fourmile Ridge to the Methow Mountains, from 6,000 to 7,700. These variations occur not only in different places, but on slopes which decline in different directions, and some part

of the apparent relief is attributed to deformation. We may therefore distinguish between those which apparently have not and those which have been tilted.

The spur which descends at the eastern end of the Entiat Mountains connects a well-preserved Cascade flat with the gorge of the Columbia, the largest stream. Lying on but parallel to an axis of uplift, its inclination has not been affected appreciably by warping, and its relief—2,100 feet—may fairly be taken as representing the facts at that place in Entiat time. The spurs of the Chelan Mountains extending north from Fourmile Ridge and those of the Methow Mountains opposite them are apparently once continuous parts of a profile now interrupted by Chelan Canyon. They do not exhibit evidence of depression or tilting toward the canyon, and their degree of relief—1,700 feet—is probably not greatly different from what was the maximum in Entiat time at that point.

The long slopes which rise 3,000 feet and more to Tyee Mountain and to the Stormy Mountain ridge are apparently not in their original attitude. The elevations of Cascade residuals and the canyons cut in these ranges show that the heights of Tyee and Stormy are due in part to local as well as to general uplift, and that the Entiat features have shared in the change of attitude. In a less degree this is believed to be true also of the Chelan Butte ridge.

GLACIATED ASPECTS OF ENTIAT HEIGHTS.

Where extended masses occur at high altitudes in the Cascade Range, the topographic features may be classed as four in number: (1) Dominant peaks, usually acute in form; (2) high serrate ridges and spurs, which are often very narrow; (3) elevated amphitheatres of characteristic glaciated form; (4) canyons, usually also glaciated. Those dominant peaks which rise approximately to a common altitude or higher are considered to be descendants of the Methow plain and its monadnocks, as already stated. Similarly, but even less adequately, the serrate ridges and glacial amphitheatres represent features of the Entiat stage. They are developed in masses which were not deeply cut by canyons of the Twisp stage, but those masses may probably have been sculptured into valleys and divides during the Entiat stage. The alternative is to assume that degradation of the Methow plain to post-Chelan aspects of glacial sculpture was accomplished without any intermediate stage of aqueous erosion. This view possibly might reasonably be held were not the Entiat stage clearly recognizable in the unglaciated area. Since the latter is the case, however, it is logical to infer the development of valleys and ridges of Entiat date, from which glaciated amphitheatres and their tangent arêtes are derived.

MATURITY OF ENTIAT TOPOGRAPHY.

In the usual threefold division of a topographic life period into youth, maturity, and old age, maturity may be used in either one of two senses, namely, to describe

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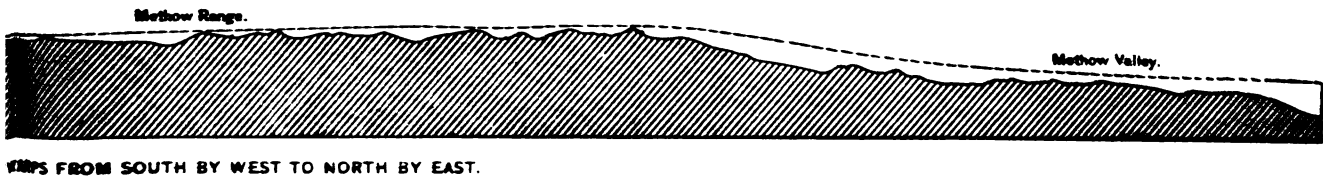
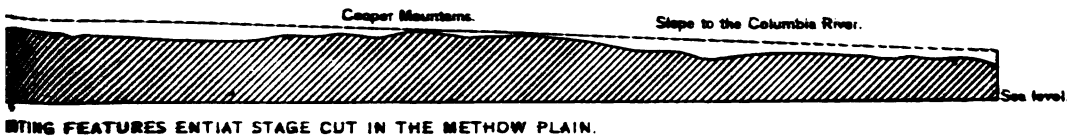
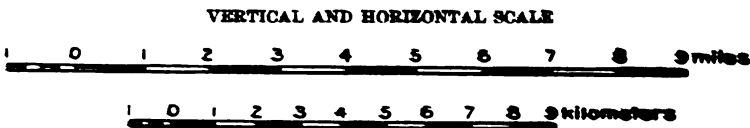
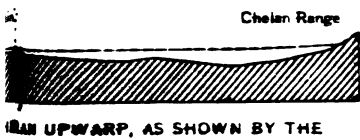
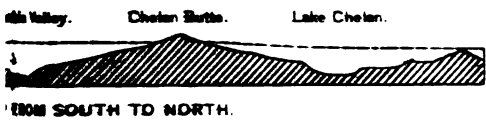
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PHYSIOGRAPHIC PROFILES
WENATCHEE-CHELAN DISTRICT
CASCADE RANGE

By Bailey Willis

Deduced from United States Geological Survey
Topographic Maps and Field Observations



REPORT OF
COMMISSIONER OF
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a long mid-interval during which the prevailing features are narrow divides, steep slopes, and V valleys; or, second, to designate with precision that exact date at which a given residual of an earlier stage is reduced to nothing and the divide begins to dwindle under the attack of opposed headwaters. In the latter sense maturity at any particular date is a term of strictly local application, since residuals do not all succumb at one time.

In the broader sense of the word, Entiat topography was mature where precipitation was heavy. In the narrower sense, it approached maturity about residuals of the Methow plain, where they still exist, but generally outside the arid region it had passed the precise instant of mature development. That is to say, the divides had become sharp and lower than the corresponding surface of the Methow plain.

ENTIAT FEATURES IN ARID AREAS.

In arid areas Entiat features have not been clearly recognized. This fact may be due to one of two conditions. In Entiat time areas now arid and high may have been similarly situated, or they may have been low. In the one case aridity, in the other lowness, would have limited erosion, and the features which developed would in either case be inconspicuous.

In the Yakima district G. O. Smith does not distinguish the Entiat stage. On the Waterville plateau and Badger Mountain it is probable that Entiat features exist, but are mantled by later deposits and obscured. The valley of the Columbia bounds these areas on the west. Its inner and outer gorges are less conspicuously separate east of the river than west of it, because landslides have generally modified the scarp, and to them the suggestive details of the profile might be ascribed; but the two episodes of development are distinguishable on the east in appropriate relations to the corresponding details west of the river. On the plateau there occur, below residual flats of Methow date, long spurs separated by lightly engraved channels. Their contours and profiles are round and gentle. They appear nowhere to be composed superficially of hard rock. Soil derived from basalt and a soft sand deposit of unknown age and origin were the materials seen. Well-filled angles and fluent curves of the landscape evidence wind work. The sculpture is that of aqueous erosion, moderately developed, and later modified by wind erosion and wind-drifted material.

In view of the stages elsewhere found, it is probable that the work of aqueous agencies was accomplished during the Entiat and Twisp epochs, and that effects of mantling are due to conditions which prevailed during the Chelan and Stehekin (Glacial and post-Glacial) stages.

On Badger Mountain ravines are cut more deeply than on the plateau and winds have had comparatively little effect; yet the slopes of the mountain exhibit remarkably slight erosion as compared with the heights west of the Columbia. It will be

shown in discussing deformation that the elevation of Badger Mountain above Waterville plateau is chiefly a growth of post-Entiat date, and therefore Entiat features are inconspicuous on the mountain, and what dissection has occurred there is of Twisp age and later.

TWISP STAGE.

CHARACTERISTIC FEATURES.

Canyons are the prevailing valley forms of the Cascade province. In elevated districts they are profound and numerous, and, having the U section due to glaciation, their volume represents a large part of that of the original uplifted mass. Between the glaciated and arid districts lies the zone of simple but energetic aqueous erosion in which unmodified canyons are most strikingly developed. In the arid region, the central plateau of Washington, canyons are deeply cut in the basalt. The most conspicuous, such as Grand Coulee, are ascribed to diversion of the Columbia during glacial time, and if that be true, do not belong to the stage here to be discussed.

The inner gorge of the Columbia between Wenatchee and Methow is a steep-sided channel cut below older topographic features in the bed rock mass of the region. Its position and proportions are such in relation to the river that there can be no doubt that the master stream cut it out. Glacial striæ were found by Salisbury on its western wall just above Chelan Ferry. A morainic terrace occurs on the eastern bank a mile below Chelan Falls, and from this southern limit of the glacier a very conspicuous system of river terraces, composed of glacial drift, extends down the valley. The gorge is, therefore, of aqueous origin and was carved prior to the latest glacial episode. As such it is a representative canyon of a pre-Glacial stage. It lies within and clearly distinct from features ascribed to the Entiat stage, and its development thus occupies an interval of time between the Entiat epoch and glaciation.

A geographic name for this stage can not well be chosen from this typical section of the Columbia Gorge, the desirable names having been applied to other uses, but it would appear from the topographic map of the Methow quadrangle that Twisp River has worked out a channel scarcely less characteristic, and the name is selected accordingly.

DEVELOPMENT OF TOPOGRAPHIC FORMS.

The Twisp cycle of topographic development was interrupted at an early phase by the advent of glacial conditions. The survival of Entiat and Methow residuals and the effects of glaciation sufficiently demonstrate this fact.

Columbia Canyon, between Wenatchee and Chelan, was cut to its present depth by aqueous corrasion before the latest Glacial epoch, since it is occupied by drift, which the river has removed down to bed rock at various points along its channel. The

canyon walls receded to some extent during Glacial and post-Glacial time, and the amount of recession is shown to be appreciable by the fact that cliffs above Chelan Falls, past which a glacier extended and over which it rose, now exhibit pinnacled profiles that have developed since the ice withdrew. But the occurrence of glacial striæ near the summit and on the river side of the cliffs indicates that the form of the canyon was not greatly different then from what it now is. This is within less than 2 miles of the end of a tongue of the wide-spreading glacier which came from Methow and Okanogan districts. The ice was probably nearly stagnant and ineffective.

In the glaciated region of the higher Cascades, the canyons are developed on a grand scale. Russell has rightly described them as extending with channels at railroad grades into the very heart of the mountain mass, and they are from 1,000 to 3,000 feet in depth. They have been widened and deepened by ice work, to what degree is yet to be determined, but apparently in some instances greatly. Nevertheless, when all reasonable allowance has been made for glaciation, the canyons which may be ascribed to corrasion during the Twisp stage were of great depth. They were relatively narrower than they now are, and their topographic development had the character of advanced youth.

CHELAN STAGE.

CHARACTER OF THE RECORD.

The climatic conditions of the Chelan stage interrupted the topographic cycle of the Twisp stage. They induced glaciation, and occasioned very pronounced phenomena of glacial erosion and glacial construction, the latter including extensive deposits from overloaded streams. Russell has already described these features in a preliminary way, and they have been touched upon incidentally in this article. The general facts are conspicuous, have been widely observed, and are published. It is expedient here to discuss only one fact, the depth of Lake Chelan, which has a possible relation also to the question of deformation.

THE BASIN OF LAKE CHELAN.

Lake Chelan occupies a canyon in granitic and gneissoid rocks. The waters are retained by a dam of drift, but discharge through the gorge of Chelan River into the Columbia, whose bed is not far from solid rock. According to the altitudes above sea of rock in place in the Columbia several miles below the junction, that of the lowest rock sill over which the waters of Lake Chelan can have escaped is about 700 feet. The elevation of the lake's surface is 1,079 feet, and its depth exceeds 1,000 feet through a stretch of 16 miles.^a The maximum sounding was 1,419 feet, i. e., to 340

^aSounded by Mr. W. G. Steel, at request of Mr. Henry Gannett, for the United States Geological Survey. MS. records.

feet below sea level, or 1,040 feet below the rock rim of the basin. The depths are given on the map (Pl. XVII), and they present an interesting problem in the question, How did the lake channel become so deep?

According to the physiographic record, the Chelan channel developed by stream robbing and became a river canyon through the usual effects of stream action, which are, however, incompetent to have so greatly deepened it. It may have been deepened by faulting or glacial erosion.

Faulting is not readily capable of direct proof or disproof in the rock structures of gneiss and granite. There is, however, throughout the Chelan-Stehekin system of channels a unity of form, which strongly suggests unity of development, and through which any hypothesis of faulting as a condition of the Lake Chelan canyon should be extended to its tributaries; but the ramifications of the system and the slenderness of the supposed downthrows are such that the hypothesis is untenable. If the area of faulting be restricted to that of excessive depth in the Chelan Basin, there is a similar peculiarity of form in the supposed downthrow and no evidence to support the proposition. We may turn, then, from the purely theoretical idea of faulting to that of glacial erosion.

Effects of glacial erosion are obvious throughout the Chelan-Stehekin system. They may be traced from the moraines of existing glaciers in the cirques about the headwaters, down the grooved and rounded canyon walls, into the waters of Lake Chelan, and out to the terminal moraine near the Columbia, in all a distance of 70 miles. Three miles above the terminus of the ancient glacier its thickness was 1,000 feet, and its surface stood about this amount above the present level of Lake Chelan. Thirty miles above its lower end, that is, near Safety Harbor Creek, the thickness of the ice was 4,500 feet, and toward the head of the lake it probably exceeded 5,000 feet. Detailed observations as to the upper limit of glaciation along the lake shore are needed, but the above statements are based upon a few points definitely noted. That this mass of ice was capable of exerting great erosive power can scarcely be doubted, but it remains to be shown that the phenomena of depth of the lake basin bear some logical relation to the probable effects of ice corrasion.

It is believed that the erosive power of ice when moving as a glacier is a function of the volume of ice, the restriction of channel, and the rate of flow.^a These factors are, it is true, in a measure interdependent, but it is not important here to separate their influences, as we can not deal with the problem quantitatively. It will suffice to show that the excavation of the channel is proportioned to the amount of ice entering from successive tributaries and that, where the volume is constant, the depth of the channel is inversely as its width.

^a Personal communication with G. K. Gilbert.

The extent of former glaciers in the Chelan-Stehekin system is indicated (with a rough approximation only to the facts, but sufficient for this purpose) in the map (Pl. VIII). It may there be noted that the drainage from a considerable area is concentrated at the junction of Stehekin and Bridge creeks, and it is at that point that the headwater canyons pass into a conspicuously wider channel, and that the stream assumes a flatter grade. Just above the junction of Agnes Creek this flat ends in an abrupt descent to a wider and lower valley floor, which extends from Agnes Creek to the head of Lake Chelan. The cross section of the canyon widens slightly, but not notably, and its depth, so far as it may be determined by the soundings in Lake Chelan, increases gradually to the junction of Railroad Creek. Abreast of this stream the valley is considerably wider, and may be regarded as a basin competent to store a considerable volume of ice. A short distance down the lake, near Prince Creek, is the upper end of the Narrows, which extend to Twentyfive Mile Creek. Here the walls of the canyon are steepest, and approach each other most nearly, and here the depth of the lake increases rapidly. Below Twentyfive Mile Creek the valley opens out and the lake basin rapidly shallows.

There is in the above-described relations that coincidence between width and depth of channel which in the single case might be considered fortuitous, but which, when oft repeated and found to be systematic, presents a strong argument for a relation between cause and effect. While the data are by no means so complete as might be wished, and while a thorough discussion of the problem would require that one should eliminate the effects of glacial and stream filling in order to arrive at a true measure of the depth of the channel, it is not probable that these subordinate factors could change the dominant relations from which it is inferred that the basin of Lake Chelan owes its unusual depth and character chiefly to glacial erosion.

A further test of this conclusion may be applied by contrasting it with other valleys in the same region, many of which have been occupied by glaciers, and none of which exhibit similar peculiarities. A thorough study of the glacial effects throughout the region should shed much light upon the nature of the phenomena, but it may here suffice to say that the Chelan case is exceptional (1) in the large volume of ice contributed from an area of approximately 350 square miles, throughout which the mountain summits range in altitude from 7,000 to 8,500 feet, and (2) in the remarkable depth and narrowness of the canyon through which the glacier was forced.

DEFORMATION.

Criteria.—The criteria according to which the nature and amount of deformation are commonly determined are of a stratigraphic character. The surface of a stratum, assumed to have been plane and observed to be flexed, is a datum from which changes of form may be deduced. In the area under discussion in the present

case the rocks are gneisses and intrusive granites, whose structures do not afford dips from which to infer the nature of recent deformation. The occurrences of basalts, which do afford such data in the Ellensburg district, are of no value in the area west of the Columbia and north of the Wenatchee, as their distribution is very limited. Jointing, the commonly developed structure of all the rocks of the district, has not been so studied as to yield results. It follows that deformation must be investigated upon a different basis, viz, chiefly upon physiographic evidence, through the warped form of the earliest recognized topographic surface, the Methow plain; and the facts described in the account of the physiographic history are thus made use of in the following discussion.

Fundamental propositions.—In the preceding discussion certain principles have been applied in interpreting the relations of physiographic features and deformation, but the statement of those principles has been deferred to this place, where it may form an introduction to the account of mountain growth. In general terms the propositions are as follows:

(1) Mountain growth involves changes of altitude of such vertical amount and such moderate extent as compared with continental areas that elongation of the earth's radii beneath the mountain mass may more plausibly be assumed to account for the elevation reached above sea level than general subsidence of the datum plane. The effect of such elongation is appropriately described as an uplift when the whole mass is considered.

(2) Uplift results in deformation of the preexisting topographic surface, which is elevated in some areas above others that may be considered relatively depressed. In what follows the term warp will be used to designate deformation of the surface, upwarp and downwarp being employed to describe, respectively, elevated and depressed areas, always the former topographic surface, and independently of the rock structure. The latter is appropriately expressed in the terms anticline and syncline.

(3) Erosion occurs only as a result of change of relative altitude, and its effects are a function of the amount of change.

(4) Other things being equal, the several sections of a river valley between source and mouth are consistently developed, when uplift has been uniform and simultaneous, within moderate limits of variation. Inconsistent sections are evidence of unequal uplift or of uplifts of different dates.

(5) At any particular stage of development in homogeneous rocks the normal grade, or slope, of a plain or river valley is variable within narrow limits only; abnormally steep, gentle, or reversed grades are effects of warping during succeeding cycles.

CASCADE UPLIFT.

The Cascade Range is an elevated mass which is observed by all who come within sight. Equally recognizable by adequate observation is the wide, tabular form of its surface, as are also the marginal slopes which connect it with lower adjacent surfaces. The gross form, all details of spurs and sculpture being omitted from consideration, is that of a broad uplift, with wide, flat top and sloping flanks.

The general fact that the uplifted surface has been eroded is obvious, and investigation of the topographic forms shows that they express several stages of development, of which the initial one was an ancient peneplain that extends over the mountain mass. The peneplain having been practically flat and low, according to its origin, and being now elevated in part, there has been warping, the amount and character of which are expressed in any section by the difference between an arc of the earth's spheroid at sea level and the flat arch of the uplifted surface. Thus we may describe the Cascade uplift as that broad and flat-topped elevation which lies between Puget Sound on the west and the central plateau of the Columbia River Valley on the east.

Height and extent.—With reference to sea level, the surface of the Cascade uplift, or the upwarp, actual and restored, varies in altitude from 6,000 to 8,500 feet throughout the area of its upper level. The maximum of 8,500 feet is attained probably north of the forty-seventh parallel and is maintained throughout more than one degree of latitude to the forty-ninth parallel. South of the forty-seventh parallel the extent and altitude of the warped plain are not well known, except that at an altitude of about 7,500 feet it forms the platform upon which stands the volcanic cone of Mount Rainier, and probably extends in a similar manner beneath Mount Adams, Mount Hood, and other volcanoes in Oregon. Its altitude probably lessens toward the south, but it is not likely that it falls below 5,000 feet along the broad axis of the uplift. The width of the uplift at its elevated plateau level is variable, but is probably rarely less than 60 miles nor more than 100. As may be seen in Pl. I, the eastern margin is crenulated, and in consequence of the fluting the width of the flat top of the upwarp is very variable, and it is possible, as suggested by Smith, that the larger marginal downwarp may extend nearly across the axis or entirely across it.

The further description is limited to the area north of the forty-seventh parallel and more narrowly to the regions which have been described in detail in the preceding chapters.

Limits of Cascade upwarp.—The limits of an upwarp are here taken to be represented by those slopes produced by warping, by which the descent from the high, flat top to adjacent areas is accomplished, without regard to effects of erosion.

In this sense the Cascade upwarp is limited on the north, according to the observations of G. O. Smith, apparently by a slope which extends across the axis of the range a short distance north of the forty-ninth parallel and leads down to a lower surface south of the Frazer River, but still high above the canyon of that stream. On the west, south of the forty-ninth parallel, according to Smith, the plateau of the upwarp extends, at an elevation of 5,000 feet, under Mount Baker, and thence descends to the Sound level by a monoclinical flexure. A degree of latitude farther south, northeast of Seattle, its western margin lies farther east. In the vicinity of Index, on the Great Northern, at the town of Snoqualmie, and along Green and White rivers, north of Mount Rainier, the descent from the mountain summits, at elevations of 6,000 to 7,000 feet, to that of the gravel plateau of the Puget Sound Basin is so abrupt as to suggest a fault scarp. There is no positive evidence of a fault as yet known, and the alternative hypothesis of glacial erosion has at least equal value at the present time. Beneath Mount Rainier and possibly to some distance west of that peak the upwarp maintains an altitude of 6,000 to 7,000 feet, and it appears in this latitude, just south of the forty-seventh parallel, to attain an expansion comparable to that which it has along the forty-ninth parallel.

The eastern limit of the Cascade upwarp may in general be described as a slope which stretches in a direction south by west from the vicinity of Osoyos Lake, on the forty-ninth parallel, to Ellensburg, and thence southerly along the west side of Yakima Valley, across the Columbia, into Oregon. This general statement of the position of the slope must, however, be qualified by the description of marginal flutings, which extend nearly at right angles to the major uplift far out into the adjacent plateau on the east and give to the axial upwarp an extremely irregular form.

The area of the upwarp thus described covers approximately 5 square degrees of the surface north of Columbia River, equivalent to about 20,000 square miles. Its further extent in Oregon has not been determined, but it is probable that it is equal to that in Washington.

MARGINAL FLEXURES.

The eastern slope of the Cascade upwarp north of latitude $46^{\circ} 30'$ has been studied physiographically by G. O. Smith and the writer with sufficient care to determine several marginal flexures, whose axes trend, in general, northwest and southeast; that is, nearly at right angles to the broad major axis of the upwarp itself. A statement of these features, so far as they may be described by the writer follows, with a brief account of the evidence according to which each is recognized.

Methow downwarp.—Methow River is one of the larger tributaries of the Columbia, which it enters about midway between the Okanogan and the Chelan, in latitude 48° , longitude 120° . The general trend of the Methow Valley is south by

east. Its headwaters are near the forty-ninth parallel, and are opposed to those of Paysayten River, which flow northerly. On the east is the Okanogan Range, and on the west the Methow, both of which are of great altitude. The elevation of the Methow above sea at its junction with the Columbia is 750 feet; at the town of Methow it is 1,158 feet, and at Winthrop, 30 miles from Methow, along the stream, it is 1,765 feet. Winthrop is situated at the principal forks of the river, and above this point the grade of the stream rises more rapidly. The aspect of the valley at the present stream level varies, according to the rocks in which it is carved. A lower section, cut in schists, is narrow and canyon-like; an upper section, comprising most of the stretch between Methow and Winthrop, is excavated in softer Mesozoic rocks, and the valley floor is wider. It has been occupied by a glacier, which has left extensive deposits, especially along the river channel. From those conditions of diversity of rock structure and interaction of stream and ice work, it follows that the physiographic aspects of the valley are not simple, and that it presents a problem in sculpture which can be fully solved only by careful observation on the ground. That observation has not been had, and the inferences which follow are based upon distant views from the Methow Mountains, study of the Methow atlas sheet, and an interpretation consistent with that of phenomena of adjacent regions.

Above the valley bottom of Methow River, between Methow and Winthrop, many hills rise to an altitude of about 4,000 feet above sea, and they are thought to represent a former level, which theoretically may be that of the Methow Valley bottom reached during the Entiat stage or may represent the older Methow peneplain. If the former be the case, the corresponding level of the Methow plain would lie at an altitude above 4,000 feet, an amount which may be deduced from the depth of the Columbia Valley at the close of the Entiat stage. The maximum determined for that valley is about 2,100 feet, as observed in the Entiat Mountains. There is no reason to suppose that the Methow has made any deeper excavation than the Columbia. Indeed, the inference would be rather the other way. Hence the position of the Methow peneplain in the Methow Valley is not far from 6,000 feet above sea, provided the general uniformity of hilltops at 4,000 feet represents the bottom of the Methow Valley in Entiat time. On the other hand, the 4,000-foot level may stand for the Methow plain, and, if so, it would coincide by gradual slope with the general altitude of that plain in the Columbia River Plateau to the southeast.

Whether the level of the Methow peneplain in the Methow Valley be 6,000 or 4,000 feet above sea, it is lower than that of the plain on the adjacent Okanogan and Methow mountains, its place in the former being probably not far from 8,000 feet, and in the latter not less than 8,500 feet above sea. Hence it seems reasonable to regard the Methow Valley as a downwarp resulting from deformation of the Methow plain.

Methow upwarp.— Southwest of the Methow Valley, in latitude 48°, is a great mass of mountains known as the Methow Mountains. In it are sunk the canyons of the Twisp and Lake Chelan, and it extends westward into the highest part of the main Cascade Range. Its area may be estimated at 1,000 to 2,000 square miles, according to the limits which may be arbitrarily drawn between it and the central Cascade upwarp. This mountain mass is designated the Methow upwarp.

The Methow upwarp is defined not only by existing topographic features, but by the altitude of the Methow peneplain and the slopes which it has assumed. In general, where most elevated, the Methow plain has an altitude of 8,500 feet, coincident with the crest of the Methow Mountains. On the east the surface descends from Navarre Peaks to the Methow and Columbia, sloping from a probable altitude of 8,000 feet to that of 3,500 or less. Toward the northeast the surface slopes to the position of the plain in the Methow Valley. On the south the descent is from an altitude of 6,000 feet to that of 3,500 feet. The southern margin is complicated by a much smaller feature, the depression within which lies the lower end of Lake Chelan, and south of which is the uplift forming the Chelan Range. The upwarp of Chelan Mountains is, in fact, a spur of the Methow upwarp, with which it is continuous along Fourmile Ridge and across Lake Chelan at the Narrows, as shown in profile.

The rocks of this uplifted mass, so far as they have been observed by Russell and the writer, consist of ancient schist, together with intruded granite, quartz-diorite, and similar igneous rocks. They afford no structure significantly related to the present upwarp, unless it be vertical jointing. The cleavage which they exhibit is probably of much more ancient date. Considered in detail, there are marked differences in structure and texture, which constitute elements of heterogeneity; but considered in mass the whole is remarkably homogeneous. The northern and western portions of the upwarp do, it is true, include areas of Mesozoic sedimentary rocks; but they may be considered as incidental, rather than characteristic, since they are quite subordinate in area and volume.

The evidence of the Methow upwarp being thus limited to physiographic phenomena, it is found first in the altitude of the Methow plain, whose position has already been described. By reference to the sections on Pl. XIX, it will be seen that it is essentially flat-topped and connected by gentle slopes with the position of the plain on three sides. Further evidence is found in the effects of corrasion, especially as exemplified in the canyons of Twisp and Chelan rivers, which are among the most profound and most sharply cut of the entire Cascade Range. That of the Twisp heads near the junction of the Methow uplift with the main Cascades, where the elevation of the flat surface is about 8,500 feet, and descends rapidly to its junction with the Methow at 1,000 feet. The greater part of this descent of 7,000

feet is made in the first 10 miles, and the canyon thence to its mouth is flat-bottomed. It is clearly the product of retrogressive activity of the stream working headwards against the slope of the upraised mass west of Methow River. The upper course of the stream is along the axis of the uplift, and there is a sharp bend by which the river turns, as it were, down the slope toward the Methow. It is possible that this change of direction is significant of an episode of capture in the history of the Twisp, which may formerly have flowed on in a continuous southeasterly course toward Libbey Creek; but no adequate study of the topographic forms has been made to determine that such was the fact. The development of the Chelan Canyon has already been described, and it has been shown that the relations between its several parts and to the old channels of Knapp and Navarre creeks are best explained as results of the opportunities for piracy which were provided by the growth of the Methow upwarp. The open valley of lower Lake Chelan is inconsistent in topographic phase with the great canyon above Twentyfive Mile Creek, and the inconsistency is regarded as evidence of the vigorous elevation from which the youth of the latter section follows. The mature aspect of topographic forms about the lower section of Lake Chelan, and the beheaded character of Knapp and Navarre coulees, are facts which show that the Lower Chelan region was relatively depressed as the Methow upwarp rose.

Chelan Butte upwarp.—South of Lake Chelan, and between it and the westward-trending course of Columbia River, is the striking eminence of Chelan Butte, having an altitude of 3,892 feet. The summit of granite dikes and schist is considered to be a monadnock, rising perhaps 400 feet above the Cascade plain. Thence westward extends a ridge having an elevation of 3,000 to 3,500 feet, which rises to the summit of Baldy Mountains, 6,432 feet, and continues northwestward in the Chelan Mountains, of which the culminating summit is Stormy Mountain, 7,219 feet. The heights of Baldy, Stormy, and other acute peaks which are largely maintained by outcrops of quartz diorite, are believed also to represent monadnocks above the Methow plain, the altitude of which is somewhat above 6,000 feet. South of this elevated ridge the Methow plain is recognized in the Waterville plateau at an elevation of 2,800 to 3,000 feet, that is at least 500 feet below its probable position on Chelan Butte, and is noted in Ribbon Mesa and in the hill rising to an altitude of 3,757 feet at 3,000 to 3,500 feet, or about 3,000 feet below its position about Stormy and Baldy mountains. This difference in altitude of the Methow plain is taken as representing the slope from the axis of an upwarp which corresponds with the trend of the Chelan Mountains from Stormy east by south to Chelan Butte, and which divides the basin of the Lower Chelan from that of the Waterville plateau. The peculiar physiographic relations of Knapp and Navarre coulees are interpreted as effects of this upwarp, across which the streams held their respective courses until

they had cut deep canyons, but by which they were ultimately retarded until they were beheaded by the Little Chelan, a tributary of the Columbia north of the axis.

Waterville downwarp.—The Methow plain is very clearly preserved in the Waterville plateau and Ribbon Mesa, the latter lying west of Columbia River at a general altitude of 2,800 to 3,000 feet. The Methow plain is lowest, so far as observed, where it is represented in two small mesas southeast of Waterville, at an elevation of 2,800 feet, and from this least altitude it rises northward, westward, and southward as would the surface of a shallow spoon. This depression, which is recognized solely on the evidence of the deformed Methow plain, is an embayment between the Chelan Butte upwarp and that of Badger Mountain, and, like the basin of lower Lake Chelan, is a minor crenulation of the margin of the Cascade upwarp.

Badger Mountain uplift.—Badger Mountain, east of the Columbia, has already been described as a broad, low elevation of the Columbia Plateau. West of the river its axial continuation is the Entiat Mountains, which, extending northwestward, lie between the headwaters of Entiat and Wenatchee rivers. This line of mountains, although divided by the canyon of the Columbia, is a continuous zone of uplift, highest toward the northwest, and sinking southeastward into the level of the central plateau of Washington. Along this summit the Methow peneplain is recognized in Badger Mountain at an altitude slightly above 4,000 feet; in the eastern end of the Entiat Range at 4,800 to 5,000 feet; 10 miles farther northwest, about Cougar Mountain, at 6,000 feet; and near the headwaters of the Entiat at probably 6,500 feet. These are maximum elevations, from which the plain slopes away to the northeast down to the Waterville plateau and Ribbon Mesa, already described, and to the southwest into the valley of the Wenatchee. Adjacent to the Wenatchee Canyon its probable altitude is not far from 4,000 feet. On the evidence of the relative altitudes of the old plain, the Badger-Entiat axis is recognized as a zone of local uplift. This inference is sustained by an examination of the canyon of the Columbia, and its relation to the Columbia Valley of the Entiat cycle, as appears from a comparison of the depth of the canyon abreast of Badger Mountain with that below Chelan Butte, and the relative altitudes of the old valley floor in the corresponding positions. The fall of the Columbia at the present time from Chelan Butte to Wenatchee, a distance of 25 miles, is about 15 feet, and may therefore be left out of consideration, the river being taken as a level datum. The depth of the canyon below the older valley at Chelan Butte is 800 feet, and abreast of Badger Mountain is 2,000 feet; that is to say, the old valley floor is 1,200 feet higher above the practically level river bed 25 miles farther downstream. As the river can not be supposed to have flowed up this slope, it is evident that the valley floor has been raised 1,200 feet more at the Badger Mountain axis than it has south of Chelan Butte. This relation demonstrates the ability of the antecedent Columbia River to maintain its course across the rising uplift.

Wenatchee downwarp and upwarp.—The Wenatchee Valley, like the Methow, is floored in part by sedimentary rocks which are more easily eroded than the schist and granite and basalt of adjacent districts; and as it has been deeply eroded by both ice and water, its physiographic features are complex. It is inferred that it corresponds to a downwarp having the form defined by the contours, and that it is limited on the southwest by the Wenatchee upwarp. The broad, evenly sloping surface of the latter is thought to represent very closely the Methow plain.

EPISODES OF DEFORMATION.

PRE-TERTIARY DEFORMATION.

The latest effects of deformation, those which have been described and which are of late Tertiary and post-Tertiary date, are but the most recent of a number of movements whose history within the Cascade province no doubt goes back to the earliest geologic events that can there be recognized. It would not fall within the scope of this article to discuss pre-Tertiary movements, even were adequate data available, but it is desirable to point out that each of the major downwarps of post-Tertiary time corresponds in position with a synclinorium in which pre-Tertiary sediments were deposited. Cretaceous strata occur in the Methow downwarp, and Eocene deposits are extensively developed in the Wenatchee and Yakima downwarps, whereas on the intervening upwarps the rocks are very much older. With regard to the Cretaceous, we can not say that the limits of geographic distribution of the sediments correspond with the depression which developed later. Indeed, the Cretaceous rocks extend across the northern part of the Cascade upwarp, where they occur upturned to dips of 90 degrees. The basins of Eocene strata, on the other hand, were of local character, and apparently do correspond somewhat closely to the respective downwarps in which they are found; but this is not true, as pointed out by G. O. Smith, in regard to the Miocene of the Yakima Valley. Rocks of Miocene, Eocene, Cretaceous, and earlier ages had suffered compressive stress and been folded during more than one epoch of deformation before the beginning of that late Tertiary topographic cycle during which the Methow peneplain developed.

From these facts it is apparent that the post-Tertiary deformation was not a peculiar effect initiated in a region previously little disturbed, but was merely the successor of other effects to which it may be genetically related, in so far as a common cause may have acted in this province from an early geologic date.

This is an expression of a fact which is of general occurrence so far as the writer's observation goes, namely, that a region of orogenic movement has commonly been the scene of repeated mountain growths widely separated in time. The reverse (that there are extensive provinces in which mountainous elevations have not developed) is also true, and the facts thus point to persistence, intermittence, and localization of the causes of orogeny.

TERTIARY AND POST-TERTIARY DEFORMATION.

All that follows relates to deformation which is later in time of occurrence than the planation of the Methow peneplain. The effects as a whole might be summed up in the phrase the growth of the Cascade Range. The general effect is the uplift of the mass from which the Cascade Mountains are carved, and the details have been described in preceding paragraphs.

Through a study of the physiography, and particularly of the Columbia River Valley above Wenatchee, two episodes of deformation have been distinguished, the first being that which occasioned the Entiat cycle of physiographic development, the second that which gave rise to the Twisp cycle. Referring to the table of physiographic development, it will be seen that these may both be considered pre-Glacial—that is, pre-Pleistocene—if the glacial conditions of the Cascade Range be found to have been restricted to a single episode; or the Entiat and Twisp cycles may both fall within the Pleistocene if two or more glacial episodes should be recognized. The writer inclines to the belief that the latter interpretation is correct, the reasons being that the condition of planation reached during the Methow cycle was probably such as to require most of Pliocene time for its development, and, further, that there is distinct evidence in the drift deposits of Puget Sound of two well-separated glacial invasions. Thus it seems probable that both episodes of growth of the Cascade Range fall within the Pleistocene division of the Quaternary.

It has been pointed out by G. O. Smith that effects of upwarping and downwarping, which in the Yakima Valley may be regarded as effects of Twisp date, correspond to anticlines and synclines that developed before the Methow plain reached its last phase. Smith does not in his area recognize the Entiat stage, and no comparison of effects of that stage with others is made by him. In the region north of the Wenatchee, however, it seems probable that upwarps and downwarps which were moderately developed during the Entiat cycle were greatly accentuated during the Twisp cycle, and that there was practical coincidence of the axes of elevation and depression during the two different episodes. Thus the Columbia Valley across the Entiat-Badger Mountain upwarp is deeper for each of the two cycles than the corresponding valley south of Chelan Butte, and it follows from this fact that the axis of upwarping was well marked in the earlier as well as in the later stage of deformation. Many of the facts of physiographic development which have already been adequately discussed point in the same direction.

CAUSES OF DEFORMATION.

DIRECTION OF STRESS.

Granting that theoretically stress may be exerted in the earth's crust from any direction, it is convenient to discuss effects of stress as due to vertical or horizontal

components, which are thus taken as being those forces that have given rise to deformation; and in what follows there is a tacit assumption that we have to deal in this particular case with effects either of vertical stress or of horizontal stress, one or the other and not both.

Vertical stresses appear at first sight more probably to have been the effective causes of vertical uplift than horizontal stresses, and the imagination appeals to the intrusion of deep-seated batholiths of granite beneath the elevated mass of the Cascade Range. In doing so it can point to pre-Eocene and Miocene intrusions of granite within the area; it may emphasize the fact that the principal monadnocks above the Methow plain are of granite Mount Stuart being the most striking and important example, and from the occurrence of granite within the areas of upwarps it may argue a coincidence of intrusion with uplift. The last-named point is, however, in a measure invalidated by the fact that the occurrence of granite beneath the later sediments which lie in the downwarps can neither be affirmed nor denied. Against the hypothesis that the deformation of the Cascade Range is due to vertical stress, and possibly to batholithic intrusion, are the generally observed facts that the rocks everywhere exhibit phenomena of jointing and flexure due to compression and that folds in the bedded basalts of the Yakima Valley are even overturned.

Turning to consider the effects of tangential or horizontal compressive stress, it is desirable to distinguish two classes of effects, one of which may be known as competent structure, the other as incompetent structure, involving shear or flow. Competent structure is exhibited in an elevation of stratified rocks such as is commonly described by the term anticline. It is developed under conditions that direct the effective component of the stress in the direction of bedding. At any point of change of dip the stress is resolved into two components, one of which continues in the farther direction of bedding, and the other acts radially to elevate the stratum with the load resting upon it. The requirements of development of the structure are those of an arch capable of supporting the superincumbent load, and the proportions of the structure are limited accordingly. From these considerations it follows that anticlines raised under the law of competent structure are relatively narrow.^a

The horizontal extent of the Cascade uplift is so great as compared with its height that if regarded as an arched structure it is exceedingly flat. Its width varies from forty to sixty times its height; and it is clear that no section of a body of rocks thus extending over two or three scores of miles can be looked upon as self-sustaining. It follows that the elevation of the range as a competent structure can not be considered.

The development of incompetent structure by compression results in shortening the mass in one direction, or in two directions; with corresponding elongation of the

^a Willis, *Mechanics of Appalachian structure*: Thirteenth Ann. Rept. U. S. Geol. Survey, pt. 2; Van Hise, *Principles of pre-Cambrian geology*: Sixteenth Ann. Rept. U. S. Geol. Survey, pt. 1.

other dimensions, or of the third dimension. The change of volume, if there be any, is assumed to be negligible; that is, in considering this type of deformation the volume is taken to be constant. The strain may be that which is described by Becker as a simple shear,^a or that which Van Hise denotes by the term pure shortening.^b The distinction lies in the internal structures developed within the mass, the change of form as a whole being the same in either case.

It has been shown by Becker, through mathematical analysis,^c that dividing planes develop through simple shear in elastic brittle masses at angles approaching 45 degrees to the direction of stress, and this theoretical conclusion has been abundantly substantiated through experiment. On the other hand, Van Hise and Hoskins have shown that in case a rock mass has been made to flow in a direction of least resistance, cleavage planes are developed in a normal attitude to the direction of stress. The structural change is apparently one involving minute movements upon many parallel planes, accompanied by the rotation of already existing mineral particles and the development of new minerals whose longest axes are parallel to the direction of flow. This structure develops only in the zone of flow and gives rise to "flow cleavage." Shear, as described by Becker, may occur in any rigid mass, in the zone of flow or in that of fracture; in the zone of flow it does not correspond with flow cleavage; in the zone of fracture it may give rise to independent "fracture cleavage" or jointing.

The structural phenomena of the Cascade Range are illustrated in the two views of Pl. XX, which were both taken within a mile of Cascade Pass at the head of the Stehekin. In *A* the cliff rising above the lake exhibits near the center of the view a number of inclined joint planes, which are sufficiently well marked to have determined the courses of the rivulets descending from the slope above. No exact observations of the dips of these planes are available, but they appear to lie at such an angle to the horizontal as possibly to come within the limits assignable to the attitude of shearing planes or fracture planes. They may be hypothetically regarded as effects of shear developed in the zone of fracture through a horizontal compressive stress. In Pl. XX, *B*, a nearly vertical cleavage structure is clearly exhibited in the details of topographic forms. It is that structure which if dominant in the heart of the Cascade uplift, and so far as macroscopic examination shows it has the characteristics assigned by Van Hise to cleavage developed in the deep zone of flow. The inference which may, with some assurance, be drawn from its widespread occurrence is that the mass of the Cascades was deformed while that portion now exposed in the highest peaks was still very deeply buried.^d

^a Finite homogeneous strain, flow, and rupture of rocks: Bull. Geol. Soc. America, vol. 4, p. 22.

^b Principles of North American pre-Cambrian geology: Sixteenth Ann. Rept. U. S. Geol. Survey, pt. 1, p. 636.

^c Ibid., p. 30 et seq.

^d For related observations see Spurr, J. E., Ore deposits of Monte Cristo, Washington: Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 2, pp. 801-802.



A SOUTHERN SLOPE OF BOSTON MOUNTAIN, SHOWING INCLINED JOINT PLANES.



B. PINNACLES SOUTHWEST OF CASCADE PASS, SHOWING VERTICAL JOINTING.



Flow cleavage and fracture cleavage structure have a common origin in compressive stress. The observed structures in the Cascade Range occur generally throughout the mountains, and can not be separated according to locality. They may perhaps be distinguished by date. If it should be found that the fracture cleavage developed in the zone of flow cleavage, the two may be assigned to a common episode of deformation, the date of which must be set so far back that the cleaved rocks were exposed through erosion before the development of the Methow plain; that is to say, to a pre-Pliocene date. On the other hand, it may be that the fracture cleavage or jointing was predominantly developed in the zone of fracture, and must be assigned to a date at which the rocks that it now traverses were nearer the surface than they had been when the flow cleavages were formed. In this case the relation of the inclined jointing to the pre-Pliocene cleavage may be such that the shearing can be attributed to that compressive stress which is thought to have caused the elevation of the Cascade mass as it is now observed. This is the conclusion reached by Spurr.^a

DIMENSIONS OF THE CASCADE BLOCK.

The speculations of the preceding paragraph in regard to the depth at which the structures may have developed naturally lead to consideration of a problem which may be stated thus: What may have been the depth of the prism which in consequence of compression horizontally was so elongated vertically as to produce the Cascade uplift. There are many qualifying factors, the data for which are incomplete or wanting; numerical results, therefore, can at best indicate only an order of magnitude, yet nevertheless there may be profit in stating the conditions of solution.

Stripped to its purely mathematical form the problem is: Given a prism, supported in isostatic equilibrium and subjected to strains in consequence of which its width, length, and height are changed, but without change of volume; and given the width before and after strain, the ratio of lengths before and after strain, and the amount of vertical elongation, to calculate the original height.

Through the courtesy of Mr. George F. Becker the following mathematical analysis is given:

UPLIFT BY HORIZONTAL COMPRESSION.

The original dimensions of a block are x , y , z , where y is vertical.

As a result of strain the dimensions become x' , y' , z' , and the volume remains constant.

Let $x' = \alpha x$ and $z' = \beta z$, then $y' = \frac{y}{\alpha\beta}$.

^a Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 2, p. 802.

In a given case suppose that we know

$$\frac{x'}{x} = \alpha, \text{ and } y' - y = b;$$

Then,

$$y' - y = y' - \alpha \beta y' = y' (1 - \alpha \beta);$$

So that

$$y' = \frac{b}{1 - \alpha \beta} \quad \dots \quad (1)$$

Here y' may be estimated on various hypotheses:

A. If $\beta = 1$, or if there is no strain in the direction of z , (1) gives

$$y' = \frac{b}{1 - \alpha} \quad \dots \quad (2)$$

B. If the strain is the same in the directions x and z , (1) gives

$$y' = \frac{b}{1 - \alpha^2} \quad \dots \quad (3)$$

C. If the strain is the same in the directions y and z ,

$$\frac{1}{\alpha \beta} = \beta, \text{ so that } \beta = \frac{1}{\sqrt{\alpha}} \text{ and (1) becomes}$$

$$y' = \frac{b}{1 - \sqrt{\alpha}} \quad \dots \quad (4)$$

To apply this general formula to the special case of the Cascade uplift we may approximate to x , the original width, on the warped surface of the peneplain; may measure x' , the present width, as the distance from the western to the eastern base of the uplift at sea level; and may determine the amount of vertical elongation as the mean elevation of the warped surface above sea level.

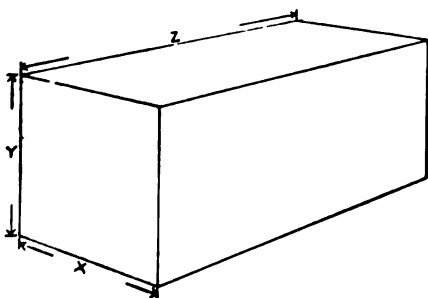


FIG. 2.—Diagram of a block.

The complete form of the upwarped surface not having been worked out, it appears best to express, between rather wide limits, the relations of the width x before strain to

the present width x' . According to an estimate based on measurements of the warped surface from Columbia River over the Methow Mountains, the width on the warped surface must exceed that on the sea-level line by more than one-tenth of a mile in a hundred miles, and this may be taken as the least possible ratio of x to x' . Whereas, on the other hand, this ratio probably does not exceed 2 miles in 100, since the width on the warped surface is an arc $A C B$ and is considerably shorter than the distance $A D E B$, which, if the mean height be $1\frac{1}{4}$ miles, is 3 miles. The altitude of the Cascade upwarp being about 8,500 feet over a large area, a mean height of $1\frac{1}{4}$ miles is probably a reasonable estimate. In latitude

47° 30' the present width of the uplift on a sea-level line is close to 100 miles. Thus, to obtain a preliminary approximation to the possible limits of the depth of the strained mass we may introduce into the equations: $x=100.1$ and 102 ; $x'=100$; $b=1.5$, all values being miles.

Table of estimated depths of strained mass of the Cascade uplift, calculated and arranged to show the probable limits according to the three equations, which express different conditions of strain.

	Values of y' in miles.					
	A		B		C	
	$y' = \frac{b}{1-\alpha}$		$y' = \frac{b}{1-\alpha^2}$		$y' = \frac{b}{1-\sqrt{\alpha}}$	
	$x=100.1$	$x=102$	$x=100.1$	$x=102$	$x=100.1$	$x=102$
$y' =$	1,500	75	750	37.5	15,000	150

The results under C may be discarded, since the equation $y' = \frac{b}{1-\sqrt{\alpha}}$ is based on the assumption that the elongation is the same in the directions of y and z ; but z is a horizontal dimension at right angles to x , and the observed facts of deformation show not only that there has not been elongation of z ; on the contrary, there has been shortening. The shortening in the direction of z is less than that in the direction of x , however, and therefore equation B does not exactly apply; but the strain is expressed by the general equation $y' = \frac{b}{1-\alpha B}$, in which B is less than α and greater than 1. If all the assumptions be valid, and if they cover the conditions of strain, the depth of the strained mass should lie between the extremes of B and A—that is, it should be more than 37.5 miles and less than 1,500 miles.

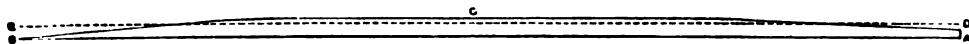


FIG. 3.—Diagrammatic section of a deformed mass.

If these limits appear to be so far apart as to leave the estimate little value, the writer would point out that the least depth indicated carries the base of the prism down into the zone of rock flow, below that superficial film in which the strength of rocks, as we know it, is a factor in transmitting stresses sufficient to cause orogenic movement. The inference is that a cause of the Cascade uplift (and presumably of related quaquaversals) is to be found in compressive stress acting on materials below the outer crust; the superficial movements, both vertical and horizontal, may then be incidental results of deep-seated strains.

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DEPARTMENT OF THE INTERIOR
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A

RECONNAISSANCE IN NORTHERN ALASKA

ACROSS THE ROCKY MOUNTAINS, ALONG KOYUKUK, JOHN,
ANAKTUVUK, AND COLVILLE RIVERS, AND THE
ARCTIC COAST TO CAPE LISBURNE, IN 1901

BY

FRANK CHARLES SCHRADER

WITH NOTES BY

W. J. PETERS



WASHINGTON
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LETTER OF TRANSMITTAL

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
Washington, D. C., August 3, 1903.

SIR: I have the honor to transmit herewith a manuscript by Mr. F. C. Schrader, entitled "A Reconnaissance in Northern Alaska in 1901," and to recommend its publication as a professional paper.

This report is based on an exploration made by Messrs. W. J. Peters and F. C. Schrader from Yukon River to the Arctic Ocean during the winter and summer of 1901. Besides important geographic results, the investigation is the first to throw light on the complex geology of the Rocky Mountain system of northern Alaska. Mr. Peters, leader and topographer of the expedition, has contributed notes on itinerary, topographic methods, and climate.

Very respectfully,

ALFRED H. BROOKS,
Geologist in Charge Division Alaskan Mineral Resources.

HON. CHARLES D. WALCOTT,
Director of United States Geological Survey.





A RECONNAISSANCE IN NORTHERN ALASKA IN 1901.

By F. C. SCHRADER.

INTRODUCTION.

Since 1898 the United States Geological Survey has been carrying on systematic topographic and geologic surveys in Alaska under an appropriation made for the investigation of the mineral resources of the Territory. This work has included not only areal surveys of regions already being developed by the miner and prospector, but also explorations and investigations of regions that are little known or entirely unexplored. As a result of these explorations a network of reconnaissance traverses has been extended over a large part of Alaska, where route surveys of this character must necessarily precede more detailed topographic and geologic mapping. They serve to outline the main geographic features of the country and afford the pioneer or prospector a guide for his journeys as well as help him to select his field of operations. The present report and maps are the results of such an investigation.

Previous to 1901 but two journeys^a which yielded any geographic results had been made across northern Alaska by white men. The first of these was made by Lieutenant Howard, U. S. Navy, in 1886, and extended from Kowak River to Point Barrow, while the second, made by J. H. Turner, in 1890, followed the one hundred and forty-first meridian from the Porcupine. The conditions under which these journeys were carried on precluded instrumental work. The present survey must therefore be considered the first made with precise instruments from the Yukon to the north coast of Alaska. In connection with the traverses made of Chandlar and Koyukuk rivers by Mr. T. G. Gerdine, and of Dall, Alatna, and Kowak rivers by Mr. D. L. Reaburn, both of the Geological Survey, it outlines some of the most important of the physical features and drainage channels of northern Alaska.

The exploration on which the following report is based was made by the writer during the season of 1901, while attached as geologist to a party in charge of W. J. Peters, topographer. The other members of the party were Gaston Philip, topographic assistant; Thomas M. Hunt, George H. Hartman, Charles H. Stuver, Ben

^aFor references and details see pp. 29 and 33 of this report.

Bennett, and Joe Edge, camp hands, all of whom rendered untiring and efficient service and manifested genuine interest in the expedition. Sections prepared by Mr. Peters are credited to him in the proper places.

As early as 1896 the Survey considered projects for reaching this unexplored field in northern Alaska, but owing to the remoteness of the region and the difficulties of transportation, no plans could be devised which did not involve the wintering of a party in this arctic country at great cost and much loss of valuable time. The first plans submitted were by Mr. J. E. Spurr, who proposed a traverse from the lower Koyukuk to Point Barrow, essentially along the route followed by Howard. The probable existence of a passable route 200 miles east of the above, between the upper Koyukuk and the Arctic slope, was not learned until 1899. The transportation difficulty, however, became less formidable when the discovery of gold on the Koyukuk, in the widespread search which attended the Klondike excitement of 1897 and 1898, led to the location of a trading post at Bergman, on Koyukuk River, near the Arctic Circle, nearly 500 miles above its mouth, and subsequently to annual visits to this post by the steamboats of a reliable company.

In the light of this later information, gained by a visit to the upper Koyukuk in 1899, the plans of the present expedition were formulated by the writer and submitted to the Director of the Survey, who approved them, and preparations were accordingly begun in the spring of 1900. The writer being otherwise engaged, the task of purchasing and assembling at San Francisco the necessary outfit, including four months' provisions for eight men, fell to Mr. Alfred H. Brooks, who was aided by Mr. R. B. Marshall.

The outfit, including canoes and supplies, was shipped from San Francisco through the Alaska Commercial Company early in the spring of 1900 and stored at the Bergman post until called for by the Survey party in 1901. From this base it was planned to carry the work northward across the Rocky Mountains of northern Alaska to the Arctic coast, and to conduct a parallel return traverse, from some other point on the coast than that at which it was reached, southward into the Koyukuk Basin, if conditions should permit. In case the return trip to the Koyukuk should be found impracticable the party was to proceed northwestward along the coast and seek relief at Point Barrow, where it was hoped it might be picked up by a returning revenue cutter or arctic whaler. In the event, however, that no such vessel appeared (as proved to be the case), it was proposed to at once continue southwestward along the coast in native skin boats or by dog sleds, as conditions might permit, until some chance vessel along the coast or some mining camp in the Nome region should be reached.

As this northern region was practically unsurveyed and much of it was entirely unexplored, it was planned to make an instrumental survey along the route of travel, which was to traverse the Rocky Mountains stretching across northern

Alaska, as already noted. It was believed that by this means, even though the actual survey was of a reconnaissance character and embraced only a narrow strip, the general physiographic features of the region would be determined and important contributions would be made to geographic and geologic knowledge. It was planned to carry on the work in as much detail as the adverse conditions would permit. It was believed by the writer that the metamorphic rocks of Paleozoic age or older, which are the source of the placer gold in the Koyukuk Basin, extended to the west, and probably formed important members of the formations which make up the Rocky Mountains, and hence valuable economic results of the investigations were to be expected. In short, the expedition was planned to collect information of all kinds relating to the geography, geology, and resources of the region; and data bearing on the preparation of the proposed general map^a of Alaska for public use were particularly desired.

Owing to the shortness of the Arctic summer it was important that progress should be as rapid as possible, regardless of the character of the weather, and as much of the energy of the party was expended in contending against the swift currents of John and Anaktuvuk rivers, the accompanying report is necessarily incomplete. For want of opportunity to make more extended observations many important problems had to be left unsolved. This is especially true with reference to the structural relations of the Paleozoic rocks in the northern part of the range, and to the relation of these Paleozoics to the Mesozoic rocks forming the Anaktuvuk Plateau or "Great Plains" on the north. The time devoted to actual field work in carrying the line from Bergman, on the Arctic Circle, to Pitt Point, on the Arctic coast, a distance of 513 miles, was sixty-five days.

For courtesies, information, and material assistance rendered on our long winter trip necessary to reach the field of work, thanks are due the Canadian Development Company and other leading trading and transportation companies, as well as numerous individuals at various points along the route of travel down the Yukon, and to the United States army officers at Eagle. In the Koyukuk region the ever hospitable hand of the prospector and miner was generously extended. Special thanks are due, also, to the Alaska Commercial Company for the excellent condition in which our supplies were delivered and wintered at Bergman, and to Mr. Gordon C. Bettles, Pickarts Brothers, and other pioneers, for valuable information concerning the people, geography, routes, trails, resources, and conditions of the country.

On the Arctic coast, where the larder and foot gear of the party had become reduced to inadequacy, the generosity of the Eskimos, manifested in their gifts of fresh fish, the loan of their mukluks, the use of their skin boats for transportation, and their aid as guides to Point Barrow, was of material value and too greatly

^aTopographic map of Alaska, compiled by the U. S. Geol. Survey, 1902.

appreciated to pass without notice. Thanks are also due to Mr. Charles Brauer and others for hospitality and courtesies received at Cape Smyth, and to Captain Ericson for transportation on the steamship *Arctic* from the Corwin coal mines, near Cape Lisburne, to Nome.

The determinations of the fossils collected on the trip and referred to in this report were made by Drs. Lester F. Ward, W. H. Dall, T. W. Stanton, George H. Girty, Mr. Charles Schuchert, and Prof. William M. Fontaine, each dealing with the fossils from the horizons of which he has special knowledge. The coal analyses and mineral tests were made by Messrs. George Steiger and H. N. Stokes in the chemical laboratory of the Survey, and the assays for gold and silver by E. E. Burlingame & Co., of Denver, Colo. Fig. 1 (p. 40) and other information bearing on the Cape Lisburne region have been generously contributed by Mr. A. G. Maddren.

METHODS OF WORK.

Dog sledding.—As the success of the work required the surveyors to reach the field before the break-up of winter, and Point Barrow by September 1, the party set out from Skagway early in February, and, after proceeding over the Coast Range by the White Pass Railway, traveled by dog sled from White Horse 1,200 miles down the Yukon to Bergman, which was reached April 10. Traveling by this means is known, in the language of the country, as “mushing,” and the traveler is called a “musher.” The “musher” does not ride on the sled, which is used only for carrying the absolutely necessary supplies and luggage, but follows the sled afoot and urges the dogs forward, or runs ahead on snowshoes to break a trail where none exists, or where, as frequently happens, it has been drifted over. To keep trail breaking and friction in travel at a minimum the dogs are all hitched tandem, from five to nine in a team. The Survey party used four teams, or about forty dogs in all. Their feed, which is given once a day, usually at night, consists of some cereal, rice, meal, or flour, cooked with meat, fish, or grease. Rice and bacon, flavored with a little dried salmon, is best. It is affirmed by experienced and reliable prospectors throughout Alaska that on arduous prospecting trips, where a man is dependent for sustenance on the food supply packed on his own back, he, too, can go farther and accomplish a greater amount of hard work on rice and bacon than on any other ration.

At the present day two classes of dogs are used for sledding in Alaska—the “inside” or native, consisting of Siwash and Malemut, and the “outside,” consisting of various breeds of imported dogs, principally from the United States. The outside dog excels in intelligence and is usually desirable for a leader, but the native dog is best for all-round service and for long, hard trips, as he requires less food and care, and having a dense pelt, much like that of the wolf, is less affected by the severity of the climate, hardship, and exposure. He is also less liable to become footsore on a trail of rough ice and freezing slush.

In "mushing," the best progress is made in relatively cool weather, at a temperature 10° or 12° below zero. As the atmosphere warms under the midday sun, the dogs, especially the natives, pant and become tired or lazy, and can not be urged. On a long trip, under reasonable conditions, 25 miles is a good average day's drive. In one instance, where the trail was good, 46 miles were covered by the Survey party in a single day. The mail carriers on the lower Yukon are known in exceptional instances to have made as high as 60 miles, the record for the Yukon country.

Camping.—During the last two years, sled journeys on the upper Yukon have been rendered less arduous by the so-called road houses, which are located at points a fair day's drive apart, and which consist usually of a log cabin and a dog kennel. Though the accommodations are of the crudest order, these places facilitate progress by affording the weary traveler much-needed shelter and rest, and by lessening the amount of outfit and supplies he is compelled to transport on a long journey. The rates charged by these road houses average about \$1.50 a meal.

Where there are no road houses, as was the case beyond Fort Yukon, the traveler at the end of the day's drive selects his camp spot for the night, and, unless provided with tent and stove, digs a hole through three or four feet of snow to the ground for a fireplace. As a shovel is rarely carried, the snow is scooped out with an axe and snowshoes. In sleeping on the snow and ice, spruce boughs, where available, form a desirable mattress. A light-weight tent, provided with broad bottom flaps and a closable entrance, besides affording protection from storm and cold, is useful in keeping the dogs from lying on one's bedding or person, as they are wont to do on a cold night. A light-weight sheet-iron stove, suited for cooking inside the tent, is very desirable, but not indispensable, as an outdoor fire is usually required to cook the dog feed.

Chronologic summary of operations.—After doing some triangulation and topographic work in the Koyukuk Valley, principally between the Arctic Circle and the sixty-seventh parallel, the party waited at Bergman for the disappearance of the snow and ice—the "break-up," as it is called; for the sheet of soft snow or slush, several feet in thickness, which everywhere overspreads the country during the thaw period of spring renders travel of every kind at that time impossible. Owing to the heavy snowfall of the previous winter and the lateness of the spring, the break-up period of 1901 was of unusual length, extending from the middle of May to June 6, about twenty-five days. During this time some astronomic observations and other investigations of a local nature were made.

Except its arching feature, the breaking up of the ice on the Koyukuk, as observed by the writer at Bergman, differed but little from that seen on most of the large rivers in northern United States. As the stream beneath the ice became swollen and distended its ever-increasing hydrostatic pressure gradually

bulged or raised the formerly level ice floor along the middle part of the river into a low arch, whose crown, by May 26, stood about 5 feet above its edges or pedal extremities, which were still frozen fast to the shores. In the meantime the excess water, increased by surface drainage due to thaw, unable to find passage beneath the ice, formed broad overflow streams, several feet in depth, coursing on the surface of the ice that formed the limbs of the arch on either side between the crown and the shore. These conditions increased until the 29th, when, at 2.30 p. m., the ice, now visible in the middle of the river only along the crown of the arch, broke or parted transversely and almost bodily moved one-eighth of a mile downstream, when it was stopped by a jam; but at 6.30 it again started and moved about a mile. Soon after this, with increased rise of the river, a general breaking up of the ice took place, and it continued to run more or less steadily until June 6, when the river cleared of it and became navigable. So far as observed, the ice rarely exceeded $2\frac{1}{2}$ feet in thickness, this comparative thinness being probably due to the protecting heavy mantle of snow. Permanent ice usually forms on the river by October 10.

Stoney^a has described a break-up witnessed by him at Fort Cosmos, on Kowak River, which was probably in most respects similar to that on the Koyukuk just described. In Stoney's description occurs the statement that "the ice suddenly became covered with water, increasing in depth on both sides of the river and decreasing toward the middle." As no reason appears to be assigned for the otherwise peculiar increase of water at the sides and its decrease toward the middle, the writer infers that this phenomenon was due to the ice-arch feature, which seems not to have been recognized by the observer at the time.

The arching feature of the ice, which seems to be characteristic in the breaking up of Arctic rivers and does not attend those in temperate zones—granting a rise in the water at the head of the rivers in both zones—is ascribed by the writer primarily to the presence of permanent subterranean frost, in whose icy grasp the edges and lateral portions of the ice become so firmly welded and held to the frozen earth along shore and the shallow riparian portions of the river bed that it is not released until thawed from the surface downward by almost midsummer suns. In temperate climates, on the contrary, where perennial underground frost does not exist, the longshore ice is the first to give way, and is often replaced by open-water leeways due to the warming and thawing influence of the underground temperature soon after the climax of winter is past.

After the break-up the party proceeded by river steamboat 80 miles up the Koyukuk to Bettles, a new supply post near the sixty-seventh parallel. From this point, commencing June 13, after doing a day's work on Lookout Mountain, the work was continued northward 125 miles, with Peterborough canoes, up a large tributary

^aStoney, Lieut. George M., *Naval Explorations in Alaska*, U. S. Naval Institute, Annapolis, Md., 1900, p. 52.

of the Koyukuk, John River,^a to its headwaters, thence by a 5-mile portage via Anaktuvuk Pass through the mountains to the upper waters of Anaktuvuk River, the large east fork of the Colville, which flows northward to the Arctic coast. These rivers were descended by canoe and the coast was reached August 15. The ice on the Colville is reported to have broken up July 16.

After mapping a considerable portion of the Colville delta, the work was continued by canoe 100 miles northwestward along the coast to Smith Bay. Here, owing to the lateness of the season, the stormy weather, and heavy surf incident thereto, the plane-table work was dropped and the journey was continued with Eskimos, who, traveling in walrus-skin boats of native make, were encountered on the journey to Point Barrow. These skin boats were found to be more seaworthy and to sail better than our Peterborough canoes.

September 3 Point Barrow was reached, where it was hoped that passage to the States might be procured on a vessel of the United States Revenue-Marine Service or some whaler; but when it was learned that all such vessels had gone, and that the ice on the ocean was expected to close within a week (September 10 being the usual date), supplies and an open whaleboat were hastily procured and the party proceeded southwestward along the coast, hoping to make connection with a whaler several hundred miles farther south, at Point Hope, where one was expected to touch to leave her native crew. By exceptional good fortune, however, on September 18, at the Corwin coal fields, 80 miles above Point Hope, the steamer *Arctic* was met, which carried the party to Nome, where it landed on September 26. From here passage to Seattle was readily obtained on one of the numerous Alaskan steamers.

Methods of scientific work.—As the Koyukuk did not break up until June, and the expedition, to be successful, was obliged to reach Point Barrow early in September, the season of work was necessarily limited to a period of less than three months, during which 500 miles had to be traveled. Since it was impossible to make more than from 3 to 7 miles a day up the swift waters of John River—and to accomplish even this required the united efforts of the entire party—it became necessary to make almost daily advances, and therefore many mountains could not be climbed that might have afforded more extensive opportunity for observation.

The topographic work was carried on by a combination of the plane table, triangulation, and tachometry, of which an account is given by Mr. Peters on pages 24–25. An independent traverse was carried on by the geologist by means of compass and aneroid to serve as an immediate base for locations in the geologic notes. In this traverse the distances were paced or estimated, and the work was daily connected with the more accurate surveys of the topographer, while from the topographic stations and other established points panoramic photographs with recorded bearings

^a Named for John Bremner, pioneer prospector and explorer, who was killed and robbed by a native in the Koyukuk region in 1888. Its native name is Alchichna, meaning *wind river*, so named on account of the fierce wintry blasts that sweep down it from the Arctic side of the divide, through Anaktuvuk Pass. See also note on p. 58.

were usually taken to show the character and relations of surrounding rock masses and to supplement topographic sketches.

So far as possible the geologic section was continuously examined, and, where conditions permitted, detailed sketches and diagrammatic notes were made of contacts, structures, mineral zones, and other important features.

ITINERARY AND TOPOGRAPHIC METHODS.

By W. J. PETERS.

Following is an extract from the letter of instructions from the Director of the Survey:

PLAN OF OPERATIONS.

"The object of the expedition under your charge is to execute a reconnaissance survey from Bergman to the Arctic Ocean. The advance will be made by ascending some tributary of the Koyukuk to the divide against which head streams flowing northward to the Arctic Ocean, and thence down such a stream to the Arctic. The return trip will be preferably overland over a route east of that traversed in reaching the Arctic, so as to obtain as much information relating to the interior as possible. If the main branch of the Colville is not descended, however, in going northward, it will probably be advantageous to return along its course. If time or other circumstances do not permit of the overland return, the most practicable alternative route will probably be along the shore via Point Barrow, until the party may be picked up by a vessel of the Revenue-Cutter Service or a steam whaler cruising in the Arctic. If relief should not be obtained from the above sources, the journey should be continued southward until a vessel becomes available or the mining camps are reached.

"As the territory to be traversed is so entirely unknown, you are especially instructed to secure all topographic and geographic information that can possibly be obtained. Sights to all mountain peaks should be taken, distances estimated if intersections are not practicable, and sketches made. In short, no opportunity should be neglected for locating, however approximately, all features that can be seen, especially in view of the fact that it is proposed to prepare a general map of Alaska on the scale of about 40 miles to the inch, and that your party will probably be the only one that will penetrate this region on a geographic mission for many years.

"You are further instructed to afford every facility to the geologist accompanying the party for the prosecution of his special work, and to consult with him in regard to all important emergencies."

In accordance with the above instructions I left Seattle February 9 on the steamer *Victorian*, accompanied by three men—Gaston Philip, assistant, Tom Hunt, and Charles Stuver. It had been arranged that the rest of the party, under Mr. Schrader, should join us at Bergman before the thawing of the ice and snow. We arrived at Skagway^a February 15, where we were obliged to wait three days on account of the snow blockade on the White Pass and Yukon Railway.

^aI wish here to make acknowledgment of the courteous treatment shown us by Mr. E. S. Busby, supervising officer Canadian customs, on presentation of the letter of Mr. John McDougald, commissioner of customs (Canadian), furnished me through the Director of the Geological Survey.

WHITE HORSE TO BERGMAN.

We left Skagway on February 18 and arrived the following day at White Horse, the terminus of the railway. We found the thermometer at 55° below zero, but it rose 30° before we started on our march. On February 21 we left White Horse with 335 pounds, principally instruments and personal baggage, on each of two sleds. The first marches were made very short to avoid the lameness which results from the vigorous exercise of untrained muscles.

Fifty-three road houses are distributed along the 369 miles of trail extending from White Horse to Dawson. This stretch of trail was broad and hard packed by pedestrian, dog, and horse. Considerable heavy freighting was being carried on by horse sled. Below Dawson the trail was narrow, in deep snow, and no wider than a dog sled. From Dawson to Eagle, a distance of 106 miles, there are but four stopping places, while farther down the Yukon they are even less frequent and usually not so well supplied, owing to their remoteness and to the scarcity of patrons. It is 240 miles by winter trail from Eagle to Fort Yukon, and along this stretch are scattered 12 road houses. During the last portion of the journey, from Fort Yukon to Bettles, a distance of 330 miles, there are no cabins, and we were dependent on our own resources. The trail followed there had been made by some parties that preceded us a few weeks, but owing to subsequent snowfalls it was frequently obliterated. This trail followed Chandlar River to Granite Creek and extended up that stream about 20 miles. It then led directly over the summit, crossed the South Fork of the Koyukuk, again ascended a divide, and finally descended into Slate Creek, another tributary of Koyukuk River. From Slate Creek to Bergman there had been much travel by prospectors sledding their summer's supplies up from Bergman.

The whole party stood the low temperature and arduous travel without bad effects. Only woolen garments were worn, which were found to give ample protection while on the march. Wolf robes, one to each man, afforded a warm sleep. Our principal discomfort was due to wet feet. Probably the best footwear for wet snow and overflowing streams are mukluks, or the native boots made on the coast.

Spruce timber was found on all the river bottoms and extending up the tributaries and gulches. Two short stretches, one on the divide between the Chandlar and South Fork of the Koyukuk and the other on the divide between the South Fork and the main Koyukuk, are above timber, but both of these were crossed in less than one day, so that every night we had firewood and some sheltering spruce, though it was small and scattered near the two divides.

Moose tracks were plentiful in the Chandlar Flats, and ptarmigan were occasionally found along the trail, but no other game was seen.

We arrived at Bettles April 14, and were hospitably cared for by Mr. Turner, the agent at this post. The following day we proceeded to Bergman to examine our supplies, which had been sent in the previous season, and found them intact.

RECONNAISSANCE UP ALATNA RIVER.

The party was now divided into two parts for the purpose of reconnoitering a route through the mountains to the Colville waters. Mr. Philip was placed in charge of one of these, and, employing a native guide, ascended Alatna River^a about 90 miles, to its eastern branch—the Kutnark. On May 5, his provisions becoming exhausted and the increased flow of water betokening a break-up, he turned back, after climbing a mountain near the mouth of the Kutnark, from which the head of this stream appeared to be completely surrounded by high mountains. The northern limit of timber appeared a few miles above the confluence of the streams. Up the western branch the timber extended as far as the valley floor could be seen.

Returning, Mr. Philip reached Bergman May 10. On this trip a few natives on their winter hunt for caribou were encountered.

RECONNAISSANCE UP JOHN RIVER.

On April 23, with the remainder of the party and a native, I started up John River. The first day's march was over the lowlands and directly toward a gap in the mountains. This direct course avoided many large bends in the river, and by night we camped close to the foot of the mountains, having made 16 miles. April 24 we entered the mountains, which rose from 3,000 to 4,000 feet above the valley, and traveled over the frozen stream, with but few cut-offs. On this trip we overtook a native woman, whose four previous camps we had passed. She was subsisting on rabbits that she caught with primitive traps. Camp was made after a march of 10 miles. On April 25 overflows were frequently encountered in the morning, but in the afternoon we were again in deep snow, which was soft, and necessitated the breaking of a trail. This was very tedious work, as the trail had to be traveled several times by all of the party and tramped down with snow shoes before it would support the sled. Sixteen miles were made in this day's march. Natives were seen in the afternoon. On April 26 we were traveling in soft, deep snow, and after going 10 miles were glad to end the weary tramp. On April 27 more natives were seen, who gave us the welcome information that little snow was ahead of us, and but little further on was the bare ice of the frozen stream. In the afternoon another camp of natives was found, and shortly after we ran onto bare ice, which was a great relief to man and dog. The day's march was 17 miles. On April 28 the traveling was on bare ice. Early in the morning we reached timber line and took on a supply of fire-

^a Called Allen River by Mendenhall in Prof. Paper U. S. Geol. Survey No. 10, 1902.

wood. Grass could be seen protruding through the snow. Wind drifts and marks in the snow indicated very strong wind storms; indeed, we had been warned by the natives last met to go into camp if a blow from the north came on. The pass was visible at the end of a march of 20 miles. I left camp standing and proceeded to explore the pass, which appeared to be short and easily passable. It was impossible to estimate correctly the length of portage for the canoes on account of the frozen conditions. On April 30, being satisfied that the mountains could be crossed through this pass, which I called Anaktuvuk, from the northward-flowing river that it leads to, we started on the return to Bergman, which, with our now lightened sled, we reached on the morning of May 3. During our absence Mr. Schrader had arrived with the rest of the party, according to the original plan. He had found the trail again covered with snow, and to make better progress had thrown away tent, stove, and other articles.

On the reconnaissance up John River, about thirty natives—men, women, and children—were counted. It is their custom to ascend the tributaries of the Koyukuk in winter to hunt. Caribou is their principal source of food. They never go beyond timber line, and it is very seldom that natives of the north coast come as far south. When the waters run they build rafts and float down, bringing skins to Bergman for trade.

It was now too late to move the cache of provisions with sleds, for the snow was fast becoming soft and the streams were beginning to run. We therefore proceeded to Bergman to await the breaking up of Koyukuk River, and spent the remaining time in starting plane-table work in that vicinity. A base was measured on the river, and four points had been occupied with plane table, when travel became impossible.

At Bergman there were three white men, and but one of these, Mr. Powers, the agent, was there permanently. Not more than half a dozen natives live near the trading post. Mr. Powers succeeded in keeping a horse all winter, feeding him oatmeal and hay, made from a coarse native grass. Several horses were also wintered at Bettles.

The cost of travel from Seattle to Bergman, via Skagway, during the winter, is about \$800 per man. The cost of freight from San Francisco to Bergman, by ocean and river steamers, was \$150 per ton.

CANOE TRIP FROM BETTLES TO POINT BARROW.

On May 29 the river ice broke, but jammed again in a few minutes. It alternately moved and jammed until June 6, when the river became practically clear of ice. On June 8 the river steamer *Luella* came down from winter quarters and carried the party and outfit up again to Bettles. Preparations were immediately begun for ascending John River, and Lookout Mountain was occupied with the plane table.

A horse was hired, to be used later in packing across the divide, and T. M. Hunt was instructed to provide himself with ten days' provisions and proceed up the valley of John River to good grazing, there to await the arrival of the party, which would work up the river in canoes. The canoes started June 13, when the water was high and very swift. Progress was best made by reaching out from the bow of the canoe, clinging and hauling on projecting bough branches and snags (which is known as "milking the brush"), and aiding the advance by the judicious use of a pole from the stern. High water gradually decreased until June 27, from which time on poling and tracking were more advantageous. Working canoes up this stream necessitated constant wading in the water at a temperature of about 50°. No ill effects, however, were observed in any of the party. Snow had by this time disappeared, except on some of the highest mountains. Occasional stops of one day each were made to ascend prominent points to carry on the mapping. The northern limit of spruce was passed July 8. Beyond this was a thin growth of willows along the stream and its tributaries. On July 9 we passed through a narrow gorge in which the stream was very swift and many bowlders occurred. This was one of the most dangerous parts of the river, and from this point to the camp of July 15 the river was a constant succession of rapids and dangerous rocks, and should not be descended in boats by any one unfamiliar with it. Between camp July 15 and camp July 16 the stream is sluggish. Above the latter point it spreads out, becoming shallow and swift. From camp July 17 the outfit was packed over by the men and horse to a small lake which empties into the Anaktuvuk, and which I have called Cache Lake. Numerous small lakes occur in the pass and along the sluggish parts of the stream.

Grayling abound in the lakes and in the pools that occur in the streams. Several caribou were shot, and signs of goats were frequent on the mountain tops. Everything having been packed over to Cache Lake, on July 22 mail and reports were intrusted to a native, together with the horse, to take back to Bettles.

On July 24 the party started down the Anaktuvuk. About 4 or 5 miles above camp July 28 the mountains end and the stream runs through rolling tundra in a fairly straight course. The channel frequently spreads out and becomes so shallow that wading had to be resorted to in order to lighten the canoes. Many caribou were seen, and one was shot. A small grove of balm of gilead, consisting of about a dozen trees, was passed August 3. Mosquitoes, which had been extremely annoying since June 14, had practically disappeared. Redtop grass was seen growing in many places, particularly at camp August 5. Between camp August 6 and the mouth of the Anaktuvuk willows became thicker, and some were several inches in diameter. Among these were scattered a dozen or two balm of gilead, which, growing to a height of about 30 feet, look gigantic in the absence of other timber. The stream flows through a country that is almost flat, covered with moss, and dotted with small lakes.

From the camp of August 8 the bluffs of the Colville were seen, and on August 9 we ran into that river, which, at the confluence of the Anaktuvuk, is 12 feet deep and about 800 feet wide, with a current running 4 miles an hour. High-water marks were 10 feet above the stage of August 9. The water was fairly clear, but increased in turbidity as we floated down. I believe this turbidity is due to the wash from the bluffs, from which muddy little rivulets continually drip with the thawing of ice. Five miles below the mouth of the Anaktuvuk a short stretch of rapid water (6 miles an hour) occurs, in which bottom was touched at $2\frac{1}{2}$ feet in midstream. Though it is possible that deeper water might have been found, I doubt if it would have been more than 4 feet at that stage. Between the rapids, shown on the map accompanying this report, the current was not over 2 miles an hour, and in them it was not greater than 6 miles. The rapids shown are all very gentle, and average not more than 100 yards in length. Four feet of water was the minimum found over all of these swift places, except the one opposite Sentinel Hill,^a where the depth was not over 3 feet. At high water, which probably occurs in June, all of these small rapids would disappear. Good grass was found on "Coal" Bluffs.

At Sentinel Hill the Colville divides and thence flows in two or more channels. The one nearest the bluffs on the western side of the valley is the deepest. Twenty-four miles below Sentinel Hill the end of the bluffs is reached, and the river, containing four islands, runs in one channel through a flat whose surface is 10 to 15 feet above sea level. The river gradually widens from 1,100 feet at the end of the bluff to 5,000 feet at the head of the delta. The head of the delta, where a very small tide is perceptible, was reached August 13. The main channel has a course N. 30° E. magnetic, and is the one farthest to the right, or the most easterly one. There was not sufficient time to follow this to the sea. It is over 12 feet deep at the head of the delta and apparently continues unbroken to the ocean. This is the only one that would be navigable for river steamers. In the endeavor to find the native village of Nigaluk, several channels were explored and the delta was roughly mapped, but it being evident that we had passed the westernmost or left-hand channel, on which Nigaluk is probably located, and not having time to return, we put out to sea. I estimated the delta to be about 20 miles wide.

Tracks of caribou were numerous on the delta, and later I learned that caribou frequent the coast to avoid the clouds of mosquitoes in the interior. On August 18 we left the delta and its mud flats and followed the coast, which varies from a low beach to ice bluffs 10 to 20 feet high. A camp of natives was seen on the delta, but little information could be obtained from them. They appeared friendly, but were not communicative. On August 20 these natives overtook us, followed by about a dozen umiaks, each containing from three to six persons—men, women, and children—on their way to Point Barrow. As they appeared to weather seas that we dared not

^a An isolated hill, so named on account of being a prominent landmark.

attempt in our canoes, and as our time was getting short and storms were brewing, I decided to induce these natives to take us in their boats.

Along the coast we were dependent for firewood on the ocean drift. This is abundant in places, but at several camps there was barely sufficient for our need. It does not compare in quantity with that found on the southern coast of Seward Peninsula. Among the logs, which were principally spruce, were noticed a redwood and one or two pines. Drinking water is to be had almost everywhere along the coast, even on the small islands, provided they are covered with moss. It is, however, often brackish.

After losing several days by storms, we arrived at Point Barrow on the evening of September 3, and at Cape Smyth about midnight. Mr. Brauer, agent of the whaling station here, gave us a warm welcome. A steam whaler had left a day or two before, and as no more vessels were expected to pass the point, he supplied us with a whaleboat with which to sail to Cape Hope, where he thought we would likely catch a vessel bound home. We started on September 5, as there was danger of the ice pack being driven in if the wind shifted to the northwest or north.

The coast from Cape Smyth to Cape Beaufort is very low, with a sandy beach, back of which bluffs rise rarely to a height of 75 feet. No high land could be discerned in the interior. Except when prevented by the storms of September 6, 9, 11, 12, and 13, we were constantly working toward Cape Hope, sailing, rowing, or towing.

In the afternoon of September 18 we sighted the funnel and masts of a steamer lying off the coal veins east of Cape Lisburne, and about dark, there being a perfect calm, this steamer, which proved to be the *Arctic*, was boarded. She was taking on a load of coal for Nome, and on the night of September 21 she steamed away, arriving at Nome September 26. Here one of the regular steamers was taken for Seattle, where the party was disbanded.

METHODS OF TOPOGRAPHIC WORK.

At intervals of about 10 miles prominent points adjacent to the river were ascended for topographic sketching on the plane table. Two signals, usually stone cairns about 6 or 7 feet high, were left on each of these points to mark the ends of the base which was to be used in determining the distance to the next station. This next station was usually selected first, so that the base might be laid off at right angles to a line joining the two stations, or as nearly so as the shape of the summit would permit. The direction of the base was always projected on the plane-table sheet to permit of the measurement of the angle between it and a line to any other station that might be occupied. The length of the base was from 300 to 600 feet, and was chosen with regard to the estimated distance and direction of the next station so as to

subtend an angle of about 22 minutes, which was measured with the micrometer screw of the alidade.

Between stations a traverse of the river was made with prismatic compass and stenometer. The plat of the traverse was transferred to the plane-table sheet and fitted to the located points. The orientation of the plane table was controlled by the azimuths, determined with the theodolite when necessary.

The method of plane-table locations was followed from Bergman to a point 20 miles beyond the summit, and, judging from intersections on points on either side of the route, it was satisfactory and sufficiently accurate for the publication scale of the accompanying exploration map. The compass and stenometer were used from a point 20 miles beyond the summit to the end of the traverse, on the Arctic coast.

PREVIOUS EXPLORATIONS.

HISTORICAL SKETCH.

Soon after the discovery of America interest was awakened in, and attempts began to be made to find, a northwest passage from the Atlantic to the Pacific Ocean, and these led directly or indirectly to explorations of Alaska and adjacent regions. The discovery of the northwestern side of America, and especially of the Arctic coast of Alaska, was preeminently the work of the English and the Russians.

For the benefit of the reader who may desire to extend his knowledge on this subject, a list of works from which much of the information here compiled has been drawn is given at the end of this chapter. Though the following sketch aims to note the more important of these discoveries and explorations, it does not attempt to be exhaustive.

Samuel Hearne,^a of the Hudson Bay Company, reached the Arctic Ocean as early as 1770 by way of Coppermine River, in longitude approximately 110°. His journey was considered as demonstrating the practicability of reaching the coast by this route and means of travel, and, what was of much greater importance, the absence of any waterway connecting Hudson Bay with the Pacific Ocean.

In 1778 Captain Cook's expedition,^b composed of the vessels *Resolution* and *Discovery*, in search of the northeast passage, explored the northwest coast from Norton Sound to latitude 70° 41', a little north of Icy Cape, where they were obliged by the ice pack to turn back. The conclusion reached at this time (and the correct one it afterwards proved to be) was that no passage existed south of latitude 65°, and that it must be sought north of Icy Cape.

In 1789 Sir Alexander Mackenzie, a member of the Northwest Trading Company, descended to the mouth of the great river which bears his name. In its delta he

^a Hearne, Samuel, *A Journey from Hudson's Bay to the Northern Ocean*, Dublin, 1796, p. 162. See also Barrow's *Arctic Regions*, p. 300.

^b Cook's *Voyage to the Pacific Ocean*, 3 vols., London, 1785, vol. 2, pp. 446-465.

located Whale Island, so named by him from the large number of white whales observed at this point. He also made observations on the tide of the Arctic Ocean. His descriptions and locations of channels were later found by Sir John Franklin to be very complete and accurate.

In the year 1815 Lieutenant von Kotzebue,^a of the Russian Navy, penetrated Bering Strait and explored the sound which bears his name, together with the northwest region as far north as Cape Lisburne. After this time we have no record of this part of the coast until the voyage of Captain Beechey, who explored the larger part of the entire Arctic coast in the years 1825-1828.

In 1826, under the auspices of the Earl of Bathurst, Sir John Franklin descended the Mackenzie to its mouth and surveyed the coast line to the west as far as Return Reef, near longitude 149° W. Acting in conjunction with Franklin, Captain Beechey, of the *Blossom*, had entered Bering Strait and sent a boat expedition in charge of Master Thomas Elson, which in the same year explored the coast as far north as Point Barrow, the northwesternmost point of the American continent.^b The exploration of the intervening distance, consisting of 160 miles of coast line, between the points reached by Beechey and Franklin on the west and east, respectively, was subsequently completed, and the north coast of the continent was outlined about ten years later, in 1837, by Dease and Simpson, by whom many of the natural features along this section of the coast were named.

In his westward advance beyond the mouth of the Mackenzie, Franklin was the first to round the great chain of the northern Rocky Mountains, consisting here, as he perceived from the coast, of several parallel ranges. These are the Richardson, Buckland, British, Romanzoff, and Franklin mountains. According to Dease and Simpson the portion of the Rocky Mountains visible from the coast does not terminate, as conjectured by Franklin, in the Romanzoff chain, but after a brief interval the Romanzoff Mountains are succeeded on the west by another chain, less lofty but equally picturesque, which was named by Dease and Simpson the Franklin Mountains. These mountains present a precipitous front to the coast.

In the days of these earlier discoverers the above-named parallel ranges, rising from 2,000 to 3,000 feet, were apparently supposed to be the final termination of the Rocky Mountains extending northward from the United States and British Columbia. The great extension of the main axis to the west along the sixty-eighth parallel and its development into a range nearly 100 miles in breadth and 6,000 feet high were unknown. Not until the performance of the work forming the basis of this report was a correct idea of this obtained.

At the same time that Franklin was conducting his discoveries westward along the coast, a detachment of his party proceeded from the mouth of the Mackenzie

^a Dall, W. H., *Alaska and its Resources*, London and Boston, 1870, pp. 329-330.

^b *Voyage of Captain Beechey to the Pacific and Behring's Straits*, London, 1836.

eastward, connecting their explorations with those previously made by him near the mouth of Coppermine River.

In the meantime, the Russians, having obtained a foothold in Bering Sea and on the coast to the south, pushed up the Kwikpak, or lower Yukon, which Malakoff,^a a creole, explored in 1838 as far north as Nulato, below the mouth of the Koyukuk, where he built a small post for the purpose of trading with the natives. In 1842 Lieut. A. Zagoskin, of the Russian Imperial Navy, explored the Koyukuk for 50 miles or more above its mouth, but explorations on the upper Koyukuk were not made until some time after much of Yukon River had been ascended and explored.

While the above explorations were being conducted along the coast during the first half of the century, in the interior the pioneers of the Hudson Bay Company, representing the English, pushed still farther northwestward from their remote outposts on the Mackenzie into regions then unknown, in quest of new fields in which to ply their fur trade. Liard and Dease rivers were explored, and in 1842 Robert Campbell descended the Pelly to its confluence with the Lewes, where Fort Selkirk was subsequently established in 1849. Also in 1842 J. Bell^b crossed the divide from the Peel River drainage into that of the Porcupine, and in 1847 McMurray descended the Porcupine to its mouth and founded Fort Yukon, on the banks of the river of this name, under the Arctic Circle, whence trade was opened with the natives. Not until two years later, however, when Campbell descended the Yukon from Fort Selkirk, was it learned that the two posts were on the same stream. The river was not ascended to this point from the western coast, however, until 1863, when the trip was made by Ivan Simonson Lukeen, an employee of the Russian American Company, and the Yukon of the English and the Kwikpak of the Russians were found to be identical. Not until then was it fully realized that the Yukon flowed into Bering Sea instead of northward into the Arctic Ocean by way of the Colville, as had been supposed, and as was represented on the maps of our school geographies until and even subsequent to that time.

In 1849 Lieutenant Pullen, of H. M. S. *Herald*, made a boat voyage from Bering Strait to the Mackenzie, and in 1850 the boats of the *Plover*, starting from Cape Lisburne, reached Bailey Island, in longitude 127°. In 1850-1854 Commander Captain McClure, of H. M. S. *Investigator*, proceeded from Bering Strait to Banks Island and Lancaster Strait, where the crew finally abandoned the ship in the ice, and by walking over the ice to Beechey Island discovered and made the northwest passage. Also, in 1850 and 1855, Capt. R. Collinson, of the *Enterprise*, sailed from Bering Strait to near King William Island, in Victoria Strait, whence, being short of coal, he retraced his course to Bering Strait. In 1852-53 the *Plover*, in command of Cap-

^aDall, W. H., *Alaska and its Resources*, London and Boston, 1870, p. 48.

^bSpurr, J. E., *Geology of the Yukon gold district, Alaska*: Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 3, 1898, p. 104.

tain Maguire, wintered at Point Barrow, in Moores Harbor, whence members of the expedition made journeys southwestward to Tasiak River and eastward along the coast to Return Reef, in longitude 150°, Maguire himself going as far as Smith Bay.

In the autumn of 1860 Robert Kennicott,^a crossing from the Mackenzie, arrived at Fort Yukon, and in the spring of 1861 descended the Yukon as far as Small Houses.

In 1865 J. T. Dyer and R. D. Cotter,^b in connection with the Western Union Telegraph expedition, are reported to have made a very creditable exploration of the country between Norton Bay and the mouth of Koyukuk River, on the Yukon.

In 1866 Ketchum and Laberge, explorers for the Western Union Telegraph expedition, ascended the Yukon to Fort Yukon with Lukeen, and later, in 1867, continued their investigations up the river as far as Fort Selkirk.

In 1867 Dr. W. H. Dall, at first in connection with the Western Union Telegraph expedition and later at his own expense, in descending the Yukon, visited the Koyukuk. Though Dall's work was necessarily of a pioneer character, his contributions to our knowledge of the interior of Alaska were very important, as they gave the first clue to the geology of the Yukon Basin.

Astronomic observations made at Nulato by Capt. C. W. Raymond, who ascended the Yukon in 1869, materially aided in more accurately locating the mouth of the Koyukuk, also the position of the upper Koyukuk, which until recently rested largely upon the astronomic determinations subsequently made by him in the same year at Fort Yukon.

The first whaler is reported to have entered the Arctic Ocean in 1848, and since then whaling has there been an important industry.

From 1881 to 1883 a signal service station, in charge of Lieut. P. H. Ray, of the United States Army, was maintained at Point Barrow, which was one of the polar magnetic stations located by international agreement. The report of this expedition and station gives statistics and valuable tables containing results of meteorologic, astronomic, magnetic, zoologic, ethnologic, geographic, and some marine observations. In making inland explorations, a part of the upper course of Meade River was mapped and the Meade River Mountains were discovered.

In 1884 additional valuable information on northwest Alaska, including the Kowak River region, was gathered on the cruise of the *Corwin*, by Capt. M. A. Healey and officers of the United States Revenue Service. Their work was subsequently continued by various other revenue cutters, some of which have visited the northwest coast of Alaska almost every year. Of these visits the most notable is probably that of the U. S. revenue cutter *Bear*, which sent out the winter overland expedition of

^a Smithsonian Reports, 1861, pp. 39-40; 1864, p. 417.

^b Dall, W. H., *Alaska and its Resources*, London and Boston, 1870, p. 277.

Lieutenant Jarvis and Drs. Call and Lopp to Point Barrow, for the relief of the whalers in the Arctic Ocean. These investigations, including the explorations of Kowak River, by Lieut. J. C. Cantwell, and of the Noatak, by Asst. Engineer S. B. McLanigan, of the *Corwin*, were continued in 1885.

In 1885 Lieut. H. T. Allen, of the United States Army, leaving the Yukon by way of the Tozikakat route, reached the Koyukuk near the Arctic Circle and ascended it to near the sixty-seventh parallel. In the same year a detachment of Lieutenant Stoney's expedition crossed from his camp on the Kowak to the lower Koyukuk by way of the Dakli.

During the winter and spring of 1886 further explorations were made on the Arctic slope by Lieut. W. C. Howard,^a who, on a trip that was productive of important results, crossed from Stoney's camp on the Kowak to the head of the Colville, Chipp (Ikpikpuk) River, and thence by way of the head of Dease Inlet to Point Barrow. Howard's trip showed that a low pass leads through the mountains from the Kowak to the Noatak; that another leads from the Noatak to the upper waters of the Colville, and that on the upper Colville in the region of longitude 156° W. the mountains are succeeded on the north by an undulating country, in which the river has a winding course, with steep banks. Farther northward, down Chipp (Ikpikpuk) River toward the coast, the undulating country is reported to give way to a "dead level waste of tundra."

To the east, Mr. R. G. McConnell, of the Canadian geological survey, descended the Mackenzie in 1888 on geologic reconnaissance work as far as the mouth of Peel River, near the sixty-eighth parallel, whence he crossed by way of the Porcupine to the Yukon.

In 1889 Mr. I. C. Russell, who as geologist accompanied the Alaskan-Northwest Territory boundary survey parties sent out by the United States Coast and Geodetic Survey, ascended the Yukon from its mouth to its source, and soon after published valuable geologic and geographic notes on his observations made along the route.

In 1890 the Arctic coast opposite Herschel Island was visited by Mr. J. H. Turner, of the United States Coast and Geodetic Survey, in connection with the international boundary survey between the Canadian Northwest Territory and Alaska. On this trip Mr. Turner made a geographic reconnaissance from the Porcupine across the Davidson Range, following the one hundred and forty-first meridian, which resulted in a material contribution to our knowledge of the mountains and country in this region.

In 1892-1894 Mr. Frank Russell, under the auspices of the Iowa State University, descended the Mackenzie, principally to make ornithologic and ethnologic investigations.^b

^aStoney, Lieut. George M., *Naval Explorations in Alaska*, U. S. Naval Institute, Annapolis, Md., 1900.

^bRussell, Frank, *Explorations in the Far North*, published by the University of Iowa, 1898.

In 1896 extensive geographic and especially geologic contributions were made to our knowledge of the Yukon Basin by a United States Geological Survey party in charge of Mr. J. E. Spurr,^a who descended the river and mapped the gold- and coal-producing districts.

Owing to the extended interest taken in Alaska by reason of the Klondike discoveries, during the years 1897 and 1898 the Koyukuk^b was visited by 1,200 or more prospectors, miners, and adventurers, many of whom ascended the river by steamboat nearly to the Arctic Circle. Some of these subsequently explored and prospected various tributaries as far up as latitude 67° 30'. Many spent the winter of 1898-99 here. During approximately the same period, 1897-98, some of the prospectors who had ascended the Kowak crossed the divide to the northeast and reached the Koyukuk by way of the Alatna.

In 1899 a United States Geological Survey party,^c conducting a reconnaissance traverse from Fort Yukon to Nulato, ascended Chandlar River, and, crossing from its headwaters, mapped the Koyukuk from near the head of its middle fork, near the sixty-eighth parallel, to the mouth of the river at the Yukon.

During the summer of 1900 a party of prospectors crossed the divide between the head of the Koyukuk and the Arctic drainage by way of Dietrich River and descended the Arctic slope along the one hundred and fiftieth meridian to a point probably a little north of the sixty-ninth parallel. From a personal interview with members of this party the writer infers that the country is passable by pack train. It is, however, mountainous and is reported to contain some glaciers of considerable size, but these are probably valley glaciers only. To the east of this the country has been traversed by deserters from whaling vessels at Herschel Island, who made their way in a destitute condition from the coast to the Yukon by way of Chandlar River. From accounts given by some of these men in a personal interview, the writer obtained the impression that this part of the region is largely a waste of rugged mountains, containing some glaciers, which are probably confined to the heads of the valleys.

During the season of 1901 a geologic reconnaissance survey was also made from Fort Hamlin, on the Yukon, by way of Dall, Koyukuk, Alatna, and Kowak rivers, to Kotzebue Sound by a party in charge of Mr. W. C. Mendenhall.^d

During the years 1901 to 1903 the region lying between the Colville Basin and the international boundary was visited, it is reported, by S. J. Marsh and T. G. Carter, two prospectors who landed at Camden Bay in the fall of 1901, and,

^aSpurr, J. E., *Geology of the Yukon gold district, Alaska*: Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 3, 1898.

^bSchrader, F. C., *Preliminary report on a reconnaissance along the Chandlar and Koyukuk rivers, Alaska*: Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 2, 1900, p. 458.

^cOp. cit.

^dMendenhall, W. C., *Reconnaissance from Fort Hamlin to Kotzebue Sound, Alaska*: Prof. Paper U. S. Geol. Survey No. 10, 1902.

proceeding inland during the following winter, prospected without success on Kugrua River, about 90 miles from the coast, during the summer of 1902, where they remained in camp during the next winter, in latitude approximately 69°, longitude 146°.

Mr. Marsh reports that this section of the country is barren or timberless, and consists largely of tundra swamps and niggerheads, underlain by rocks which he regards as a geologically young and nonmineral-bearing limestone formation. The country is reported to be plentiful in game, of which caribou, bear, wolves, foxes, and ptarmigan are the most important, the latter being very abundant. Kugrua River, which flows northward into the Arctic Ocean, is estimated to be about 280 miles long. Besides the Kugrua, four other rivers of considerable size are reported to enter the ocean between the Turner and the Colville.

In the spring of 1903 Mr. Marsh crossed the divide to the south of the Kugrua, where he reports that he found a mineralized zone on the headwaters of Chandlar River, which stream he descended to the Yukon.

During the summer of 1903, it is reported, a prospecting party, of which James L. Reed and Walter Lucas were members, crossed from the Kowak by way of the headwaters of the Noatak and of the Alatna, a tributary of the Koyukuk, to the Killik, a tributary of the upper Colville, which they descended to its mouth. The Killik is said to transport much floating ice, to be about 100 miles long, and to have many rapids in the lower 50 miles of its course. They then explored the Colville for a distance of 175 miles below the mouth of the Killik and for 50 miles above it, and found this section of the Colville to be 400 to 500 yards wide and navigable, with a current of about 6 miles an hour. The topography of this part of the basin is reported to be undulating, with low hills, as described by Howard, and the rocks to consist of a sandstone formation in which thick veins of bituminous coal crop out along most of the creeks. This coal was burned by the prospectors in their camp fires. As no trace of gold was found, the formation is inferred to be probably non-auriferous.

Excepting willows, which occur along the streams, and are often of large size, the country is timberless; there is no spruce. Game is present and caribou are plentiful.

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POPULATION AND CONDITIONS.

ON THE KOYUKUK.

Natives.—So far as can be judged, there are about 100 native inhabitants on the upper Koyukuk. The United States census for 1900 places the population of Peavey village, near the South Fork of the Koyukuk, at 35. The settlements of the Koyukuk natives, each consisting usually of a few cabins and tents, are sparsely scattered along the river from below the Arctic Circle to the sixty-seventh parallel of latitude. They are generally located at the mouth of some tributary stream, as in the case of Alatna River, Pickarts Creek, and Kanuti River. Their village at Bettles, which is larger than most others, forms an exception to the above rule, and exemplifies the disposition of the natives to remain near a trading post and the abode of white men.

At the post the natives are frequently employed by the whites for boating, sledding, and other work, for which service they receive provisions and clothing, which, added to what they get of game and fish, make up their living. They take but little interest in prospecting or mining. Apart from the partial sustenance they procure at the post, their chief source of food and clothing is the wild Alaskan reindeer or caribou, bear, salmon, whitefish, rabbits, grouse, and ptarmigan.

The Koyukuk country is also visited by the Kowak natives from the northwest, a more hardy and industrious race than the Koyukuks.

Whites.—After the exodus of the thousand or more inexperienced adventurers who in the Klondike rush reached the upper Koyukuk in the fall of 1898, wintered there, and disappeared from the country almost with the ice when navigation opened in the following spring, about a hundred sturdy men, mostly prospectors and miners who had arrived with the influx the preceding fall, remained. Stimulated by the discovery of placer gold, they continued to prospect and began to mine some during the summer and engaged to some extent in development work during the following winter. In the meantime, especially in the months of February and March, 1900, as the reports of the presence of gold became authenticated, many people from various camps along the Yukon were attracted thither. This materially increased the mining activity of the district, which in a general way has continued to the present time; so that in 1901–2 about 200 white people, mostly miners and prospectors, wintered there, and at present^a (1903–4) they number about 350, the most of whom are prospecting or doing development work about the mines. Besides the people who winter there, many others reside there during the summer only, while working their claims. Since the discovery of gold the wage for the district has been \$12 a day. Ground that will not yield this amount or more is not worked. Board is \$6 a day.

Transportation and means of travel.—Since 1900 there have been two supply posts^b in the country, Bergman and Bettles, both operated by the Northern Commercial Company, successor to the well-known Alaska Commercial Company. Of these posts, the lower and usually the best stocked is Bergman, at the head of steamboat navigation, near the Arctic Circle, and about 450 miles above the mouth of Koyukuk River. At high water, however, in both spring and fall, steamboats ascend with freight to Bettles, near the sixty-seventh parallel, about 80 miles above Bergman. From Bettles, which has become the leading distributing point for the country, the supplies are conveyed to the various mining camps, about 75 miles farther up the river, by rowboat during the open season, or, preferably, by dog sled in the winter. The country is also reached by pack train from the Yukon in summer, by way of Chandlar River from Fort Yukon and by way of Dall River from near Fort Hamlin, the distance in each case being about 150 miles. Pack horses have been used to some extent during the last few summers, both for packing and for working at the mines, but the heavy snowfall renders the horse unfit for winter use. A shorter route than either of the above, leaving the Yukon at a point about midway between the Dall and the Chandlar and about 100 miles from Coldfoot direct, is now being investigated.

^a Information on present (1903) conditions in the district has been contributed by Mr. L. M. Prindle, a member of the Survey, to whom it was recently furnished by miners en route from there to the States.

^b Besides these, the company keeps a branch post at Coldfoot.

The principal post-office is at Bettles, but mail is also distributed from Bergman and from Coldfoot, at the mouth of Slate Creek. The judiciary of the district, consisting of United States commissioner, probate judge, coroner, and recorder, is located at Slate Creek, near the center of the mining region. Since early in 1901 these offices have been held by Judge D. A. Mackenzie, a former citizen of Seattle, and one of the pioneers of the Koyukuk country.

The placers.—The gold placers are shallow deposits, well suited for development by men of moderate means, who are able and willing to work. No one, however, should go to this country intending to mine without taking with him a year's supplies, commonly known as a "grub stake," or its money equivalent, about \$1,000. The mining period is confined to about 2½ months in summer.

The placers now being worked extend over a large area, but occur chiefly on the middle drainages of the Middle and North forks of Koyukuk River, where they embrace a score or more creeks with their tributary gulches, some of which have been discovered recently. The gold is coarse. The yield of the district to date, as shown on page 102, is about \$717,000.

ON THE ARCTIC COAST.

Natives.—With the exception of about a dozen white persons at Cape Smyth, near Point Barrow, and some at Point Hope, the bleak Arctic coast of northern Alaska is inhabited only by the Eskimo. From the international boundary to Point Hope, through a distance of 800 miles, the native population aggregates about 1,500 persons. Their settlements are far apart. The principal ones are those of Point Hope, Cape Smyth, Nuwuk at Point Barrow, Nigaluk at the mouth of the Colville, and Barter Island about 150 miles farther east. There is also a settlement at Herschel Island, east of the international boundary, and one in the Mackenzie River delta. There is yearly communication between all these points. The census of 1900 credits Point Hope village with a native population of 314, and the settlement of Cape Smyth, probably including Nuwuk,^a with a population of 623. That of Nigaluk, at the mouth of the Colville, also probably amounts to about 200. There are also smaller settlements or single huts at points along the coast, as at Wainwright Inlet and Icy Cape, which are occupied in winter but generally vacated in summer.

The principal food supply contributed by the sea is derived from the whale, walrus, seal, polar bear, and some small fish. Salmon, herring, smelt, and other small fish are found in the inlets and rivers. During the summer season there are large numbers of geese and ducks. The principal land quadrupeds are Alaskan wild reindeer or caribou, brown and black bear, wolverine, marten, wolf, hare, lynx,

^a Nuwuk, meaning in Eskimo "the point," is the name of the native village on Point Barrow proper, while the main settlement of the white people, where are the trading post, mission, and post-office Barrow, is 9 miles southwest of Point Barrow, at Cape Smyth, to which the name Point Barrow is generally though somewhat incorrectly applied.

fox, beaver, muskrat, and lemming. Of these, the most important for food and clothing, and fortunately the most abundant, is the caribou, whose migrations the natives follow. Berries and roots are also used for food by the natives.

As the coast region is destitute of timber, affording only a few dwarfed willows at distant points along the rivers and inlets, the principal fuel of the natives is drift-wood, most of which has been discharged into the ocean by the larger arctic rivers, whose headwaters lie in forested regions. This is fairly well distributed along the coast, but is not so abundant as often supposed.

The Alaskan Eskimos, so far as seen by the writer, are not the dwarfed race of people they are often depicted. The men will probably average nearly 5½ feet in height and 150 pounds in weight. They are generally robust, muscular, and active, inclining rather to angularity than to corpulence. The face may be described as flat, broad, and rounded, with high cheek bones. The eyes are brown or dark and the hair is black. As a people they are relatively intelligent and industrious and appear to be reasonably honest and moral. They are hospitable, good-humored, and cheerful, apparently free from care, and generally patient and tactful in manner. Their feelings have been described as lively but not lasting, and their temper is frequently quick but placable. The conjugal and parental affection is strong. Though thankful for favors, their gratitude is of short duration.

Owing to its mixture with that of representatives of other races who reach the arctic regions, principally on whaling vessels, the blood of the Alaskan Eskimo is rapidly losing its purity. Children of pure Eskimo blood are reported to be very few.

Whites.—There are at present about a dozen white persons living at Point Barrow. There is a mission school here at present, in charge of Doctor and Mrs. Call. A trading post, maintained here by the Cape Smyth Whaling and Trading Company for purposes of trade with the natives and whalers, is now in charge of Charles Brauer. The keepers of the post engage to some degree in whaling, in which they employ the natives. Early in April the whaling parties proceed by dog sled 10 or more miles out over the ice to the open sea, where they pursue their calling in open skin boats.

Point Barrow is almost annually visited by vessels of the United States Revenue Service and by various whaling vessels. Ten of the latter are reported to have called there during the summer of 1901. Whaling in this part of the Arctic Ocean has been carried on with varying success by several companies during the last half century, but is now reported to be on the decline. The pursuit is hazardous, as the vessels are often caught in the ice pack.

In 1901 effort was being made by a Japanese to establish a small trading post at the mouth of Staines River, near the one hundred and forty-sixth meridian.

Transportation and means of travel.—Transportation and travel in this barren region is principally by native skin boats along the coast and streams during the short open summer, and by dog sled over the snow and ice in winter; though the north coast Eskimos sometimes make trips into the interior from the mouth of Chipp (Ikpikpuk) River southward to the head of Colville, Noatak, and Kowak rivers. Their knowledge of the country in general is not definite beyond a distance of 40 or 50 miles from the coast.

The native skin boats, or umiaks, are usually made of walrus skin. Being light, flat-bottomed, and responsive to sail, they are admirably adapted for use in the shallow waters of the deltas and tidal mud flats so characteristic of the Arctic coast, and for small craft are very seaworthy.

TABLE OF DISTANCES.

The following table, prepared by Mr. Peters, is here inserted to afford an idea of approximate distances along the route of travel.

<i>Distances up John River.</i>	
Mouth of John River.....	0
Fool Creek	51
Hunt Fork	92
Rocky Gorge	106
Anaktuvuk Pass	120
Cache Lake.....	125
<i>Distances down Anaktuvuk and Colville rivers.</i>	
Cache Lake.....	0
Canyon	43
Small grove Balm of Gilead.....	54
Ice field.....	63
Two native huts	101. 5
Mouth of Anaktuvuk River.....	114
Rapid ^a	117
Rapid ^a	119. 5
Rapid ^a	121
Sentinel Hill	140
Rapid ^a	143
Rapid ^a	147
Rapid ^a	157
Ocean Point	164
Head of delta.....	192. 5
Arctic Ocean	212

^a These rapids are short stretches of the river, running about 6 or 7 miles an hour, with no rough water.

Distances along coast from Colville River to Cape Smyth.

Middle channel of Colville River.....	0
West channel.....	17
Cape Halket.....	67
Pitt Point	90
Simpson Cape	137
Tangent Peak.....	189
Point Barrow.....	198
Cape Smyth	207

GEOGRAPHY.

LOCATION AND GENERAL FEATURES.

The region here considered, as shown on the outline map, Pl. I, lies in northern Alaska, mainly in its middle part. The area covered by the detailed maps (Pls. II and III) trends in a nearly northward direction from the sixty-sixth parallel of latitude approximately along the one hundred and fifty-second meridian to about the seventy-first parallel at the Arctic coast, a distance of about 400 miles. The maps are based entirely on observations made during the present exploration along Koyukuk, John, Anaktuvuk, and Colville rivers, except that to these have been added some notes of observations made by Mr. T. G. Gerdine and the writer in the Koyukuk district in 1899.

Geographically the region consists of three well-marked provinces—the mountain or middle, the Koyukuk or southern, and the Arctic slope or northern.

Orographically the mountain range, forming the middle province, is regarded as a northwestern continuation of the Rocky Mountain system of the United States, which, extending northwestward through Canada nearly to the Arctic Ocean, bends abruptly to the west beyond the Arctic Circle and trends nearly westward across northern Alaska, forming the great trans-Alaskan watershed between the Yukon Basin on the south and the Arctic Ocean on the north. In its northward and finally westward course the range forms a prominent feature of the “concentric” orography of Alaska, and embraces in its southward-facing curve the great basin of the Yukon and the well-known, but not always well-defined, Yukon Plateau.

From its character and relation to the range, it seems probable that the gently rolling plain bordering the mountains on the north and sloping gently to the Arctic Ocean may be physiographically correlated with the Great Plains in western United States, while the basin of the Yukon corresponds to the great Interior Basin of the West, lying between the Rocky Mountains and the Coast Range.

In their trend across Alaska the mountains agree with those in the Canadian territory adjacent to the east, which extend nearly to Mackenzie River. In the

region north of the mountains, both in Canadian territory and in Alaska, the valleys trend northward toward the Arctic coast, while those on the south trend southwestward toward the Yukon.

Considering the country more in detail, we may note that the line of profile extending through the region as a whole, in a north-south direction (see Pl. II), beginning on the south, at the sixty-sixth parallel, traverses for the first 120 miles of its course an undulating country whose low, rounded hills attain elevations of from 1,000 to 3,000 feet. It then crosses a rugged range of mountains 100 miles wide and about 6,000 feet high, whence it descends steeply to the elevation of 2,500 feet at the inland edge of a gently northward-sloping plateau or rolling plains country (Pl. IV). It then traverses this rolling plain for 80 miles, and thence passes for about 80 miles through a nearly flat, tundra country or coastal plain to the Arctic coast.

To facilitate description each province will be treated separately.

MOUNTAIN PROVINCE.

The most striking is the middle or mountain province, which, as noted, consists of an inland range of rugged mountains trending east and west across the field between latitudes $67^{\circ} 10'$ and $68^{\circ} 25'$, as shown on the topographic map, Pl. II. These mountains here have a width of about 100 miles and an average elevation of about 6,000 feet.

It is unfortunate that the term Alaskan has already been applied to a local range lying south of the Yukon, as that name would seem to be the most fitting term by which to designate this portion of the great Rocky Mountain system, which here extends east and west entirely across the northern part of the Territory. That these mountains are regarded as a northwestward continuation of the Rocky Mountain system has been noted, and the term Rocky Mountains has been broadly applied to them on the map.

That portion of the main range lying between the international boundary and Mackenzie River has been called the Davidson Mountains, while to the several small groups on the north, between the main range and the coast, and extending from the one hundred and thirty-eighth to the one hundred and forty-eighth meridians, the names Richardson, Buckland, British, Romanzoff, and Franklin have been applied. They are all probably more or less closely connected with the main range, from the northern side of whose great bend to the southwest between Mackenzie River and Colville River they seem to branch. So far as known they trend in a general northwestward direction, but have a somewhat imbricated relationship, each group tending to overlap the inland part of the one next to the west. They seem to represent the northward dying out of the range near the Arctic coast. If they are considered a part of the range in the region of the one hundred and forty-seventh

meridian, they give to it a breadth of about 210 miles. In elevation these groups lie generally between 2,000 and 4,000 feet, while the height of the main range near the international boundary is from 5,000 to 7,000 feet. From this point, with but slight if any decrease in elevation, the range continues westward to the one hundred and fifty-third meridian, beyond which, in the region at the head of Colville and Noatak rivers, it diminishes in height, and seems to divide into two parts or ranges. Of these, the northern range, continuing westward, terminates in the low mountains and abrupt sea cliffs of Paleozoic rocks at Cape Lisburne (see Pl. V and fig. 1), while the southern forms the divide between Noatak and Kowak rivers.

ENDICOTT MOUNTAINS.

GENERAL FEATURES.

It is probably to the range between Noatak and Kowak rivers, as seen from Lookout Mountain, on the Koyukuk, that Allen in 1885 gave the name Endicott Mountains. Though the name appears on Allen's map,^a and is referred to in the text of his report, it is not known to have come into use or to have appeared on any of the numerous succeeding Alaskan maps. Allen refers to the mountains of this region as comparatively low, and says the highest are the Endicott Mountains, between Koyukuk and Kowak rivers, which, extending northward, were supposed to contain the headwaters of Colville River. The highest peaks were estimated at 4,000 feet. As printed on Allen's map, however, the term is given a broader significance, applying to practically the entire portion of the range embracing the headwaters of the Koyukuk and the sources of the drainage ways which flow in an opposite direction into the Arctic Ocean, between the one hundred and forty-fifth and one hundred and fifty-fourth meridians. As the term embraces and seems fittingly to apply to all that part of the range considered in this report, it will here be retained, and the mountains will be referred to in this report as the Endicott Mountains.

Where crossed by the Geological Survey party the range lies between the rolling, hilly country of the Koyukuk Basin on the south and a very gently undulating plateau country on the north. On the south the rise from the rolling country to the mountains is by foothills, but rapid. On the north the mountains break off abruptly, much as they do along the edge of the Great Plains in western United States.



Fig. 1.—Sketch section of supposed Paleozoic rocks on the coast south of Cape Lisburne.

^a Allen, Lieut. H. T., *Reconnaissance in Alaska*, 1885, Washington, Government Printing Office, 1887.





Pronounced faulting and uplift are evidenced by marked deformation of the strata and in some places by fault scarps miles in extent.

The comparatively regular southern edge of the range trends approximately east and west, in latitude $67^{\circ} 10'$, while the northern edge, where it was crossed, in the region of Anaktuvuk River, latitude about $68^{\circ} 25'$, presents a concave front to the north, as shown on the maps (Pls. II and III). This crescentic feature is repeated by several low concentric ridges in the Anaktuvuk Plateau to the north. These seem to have been formed by a part of the same orographic uplift as the main range, for they lie parallel with its front and grow weaker and finally die out northward with increase of distance from the seat of maximum uplift.

West of the Anaktuvuk the crescentic front of the range soon gives way to a more nearly westward trend, bearing in the direction of Cape Lisburne. To the east of the Anaktuvuk, however, the curved front continues in a northeasterly and finally north-northeasterly direction, so that in about latitude 70° and longitude 147° it reaches a point within 35 miles of the coast, where it merges with the Franklin Mountains, one of the northern groups previously noted. From this point eastward to Mackenzie River the northern edge of the mountains continues near the coast.

Along the one hundred and fifty-second meridian the range is somewhat higher in the northern than in the southern part, and contains two distinct orographic axes, the surface of the northern having an elevation of a little more than 6,000 feet, and that of the southern somewhat more than 5,000 feet. Between these axes there is a slight depression, where the surface has apparently been somewhat more rapidly reduced by erosion in soft rocks. This is notably true on the west side of John River, somewhat north of the middle of the range, where in the region of the sixty-eighth parallel and the one hundred and fifty-third meridian the country between the head of Hunt Fork, which flows southeastward into John River, and the head of the Colville on the northwest, probably does not exceed 5,000 feet in elevation.

The topography of the range varies, depending on the character and structure of the rock formations. That of the Fickett series, composed of phyllites, slates, quartzites, and conglomerates, is characterized by sharper crests and peaks than the limestone areas, whose ridges, being broader and more rounded, are often studded by knobs and bordered by steep cliffs, with extensive slopes of heavy talus at their foot.

Though marked cliffs and precipices occur, the side slopes of the valleys, as shown in Pl. VI, A, can generally be ascended without difficulty. They are moss covered to within about 2,000 feet of the top of the mountains, where steeper slopes of barren rock and talus begin. Exceptions occur in the faulted Paleozoics in the northern side of the range, at the head of the Anaktuvuk, where some scarps rise abruptly to a height of several thousand feet above the valley.

ANCIENT PLATEAU FEATURE OF ENDICOTT MOUNTAINS.

Where best observed on this reconnaissance, principally on John and Anaktuvuk rivers, a view across the top of the range presents the general appearance of an ancient plateau or peneplain from which, by deep dissection, the mountains have been carved. The former surface of the plateau is evidenced by numerous closely crowded peaks, rising generally to an elevation of 6,000 feet, where they present an even sky line, as shown in Pl. VII, *A* and *B*. For this plateau feature of the range the name Endicott Plateau is proposed. About 4,000 feet below this level lie the floors of the main valleys, at an elevation of about 2,000 feet; and the open Anaktuvuk Pass, near the northern edge of the range, between John and Anaktuvuk rivers, is at an altitude of scarcely 2,500 feet.

Since for geologic purposes the accompanying geologic section (see section on Pl. III) is confined to the line of traverse along the valleys, where the elevation has been much reduced by erosion, the profile of the section does not express the plateau character of the range. This feature is probably best shown in the illustrations forming Pl. VII, which are reproduced from photographs taken on the upper part of John River, near the top of the range, at an elevation of about 6,000 feet.

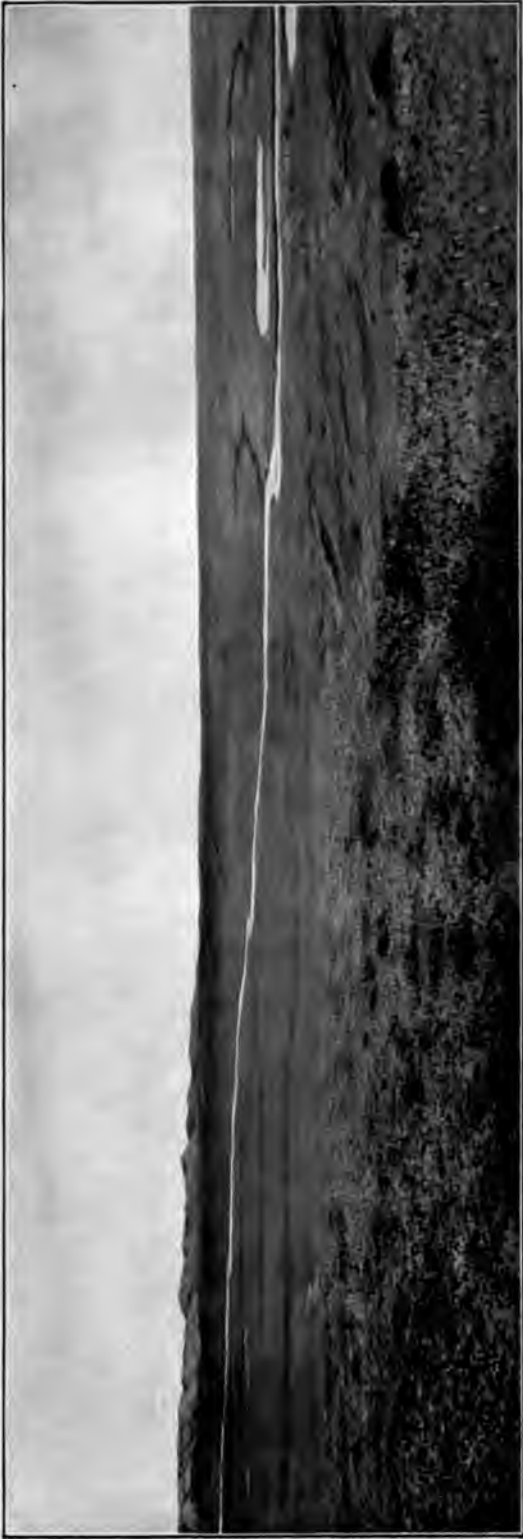
It seems to the writer not improbable that, as our knowledge of the physical geography of Alaska becomes more complete, it will be found that the Endicott Plateau, including its extension to the east, possibly beyond the Davidson Mountains, may be correlated with the Chugach Plateau, a similarly dissected plateau surface, which is observed in the westward continuation of the St. Elias Range, at an elevation of about 6,000 feet.^a

The interstream areas, which in general rise to the surface of the Endicott Plateau, are rarely flat topped, but consist of a network of peaks connected by irregular and often sharp-crested ridges. Only occasionally does an isolated peak rise a little above the general level of the plateau. None that could be observed are monadnocks.

The relation of the Endicott Plateau to the supposed Yukon and Koyukuk plateau features, to be considered later, is diagrammatically illustrated in fig. 2 (p. 44). So far as known, no rocks younger than Lower Carboniferous have been found in the Endicott Plateau. But as it seems not improbable that Upper Carboniferous and possibly even Lower Mesozoic rocks may be present in the Fickett series, it does not seem safe to suggest for the plateau an age earlier than Mesozoic. It seems undoubtedly older than the supposed Yukon Plateau, which in turn is considerably older than the Koyukuk Plateau, as the latter lies at a much lower level and is composed of rocks which are in part Cretaceous, and some possibly younger.

^a Schrader, F. C., and Spencer, A. C., *Geology and Mineral Resources of a Portion of the Copper River District, Alaska*, a special publication of the U. S. Geol. Survey, 1901.

See also Schrader, F. C., *A reconnaissance of a part of Prince William Sound and the Copper River district, Alaska*: Twentieth Ann. Rept. U. S. Geol. Survey, pt. 7, 1900, p. 375.



A. INLAND EDGE OF ANAKTUVUK PLATEAU AND NORTH BASE OF ENDICOTT MOUNTAINS.
From surface of the plateau at 2,200 feet; looking southwest.



B. LISBURNE LIMESTONE AND FICKETT SERIES IN ENDICOTT MOUNTAINS AT HEAD OF JOHN RIVER.
From an altitude of 6,000 feet; looking west. Fickett series is in left background.

Since the Yukon Plateau, as to whose age there is slight difference of opinion, has been shown by Dawson,^a Spurr,^b and other writers to be due to Eocene or early Neocene erosion, if the present writer is correct in his supposition concerning the representation of this plateau feature in this northern field, the interrelations of the several features here make it obvious that the Endicott Plateau, which is certainly post-Lower Carboniferous, must be at least pre-Neocene and is probably considerably older, and that the Koyukuk Plateau is at least post-Eocene and possibly considerably younger.

DRAINAGE.

In the portion of the range crossed by the Survey party the drainage is principally southward into the Koyukuk. The master stream is John River, which rises near the northern edge of the range. The main drainage ways are therefore transverse, extending across the strike and trend of the rocks, as well as across the trend of the range. The small tributaries, being nearly always controlled by rock structure, flow in general along the strike and enter the master stream at right angles, producing a rectangular drainage system.

Though John River Valley is intramontane and contains some canyons, it is broad and in general open. A portion of it, near the middle part of the range, seems to lie in a syncline in the Fickett series, trending a little east of south. The valley probably averages about $1\frac{1}{2}$ miles in width, from base to base of the mountains. Portions, however, are much wider and contain flats, through which the river freely describes great bends from side to side. The present stream channel has apparently been sunk into several older valley floors, as is shown by the bed-rock benches along the sides of the valley. Of these benches the most pronounced occur at heights of 1,700 feet, 600 feet, and about 100 feet above the present stream, and seem to mark stages of comparative rest in the progress of orographic uplift. It is probable that the 600-foot bench may be correlated with the benching noted on the Koyukuk, in the region of Red Mountain.^c

At the head of John River, benches sloping northward against the present drainage seem to denote that a considerable area lying at the head of this stream formerly drained northward, through the Anaktuvuk and the Colville, into the Arctic Ocean, instead of southward, through the Koyukuk and the Yukon, to Bering Sea, as at present.

The bed-rock benching and the topography of the lower side slopes of the valley are frequently found to have been materially modified by ice action, which has

^a Dawson, G. M., The physiological geology of the Rocky Mountain region in Canada: Trans. Royal Soc. Canada, vol. 3, 1890, sec. 4, pp. 1-74.

^b Spurr, J. E., Geology of the Yukon gold district, Alaska: Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 3, 1898, pp. 257-265.

^c Schrader, F. C., Preliminary report on a reconnaissance along the Chandler and Koyukuk rivers, Alaska, in 1899: Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 2, 1900, p. 468.

eroded the rocks and brought down deposits of gravel and drift, as shown in Pl. VI, *B*. Such deposits, however, rarely attain a thickness of more than 100 feet.

The John River system, just described, is believed to be a fair type of the other adjacent drainage systems of the mountains, such as Hokotena River or Wild Creek and North Fork, which trend parallel to it and also flow south into the Koyukuk.

KOYUKUK PROVINCE.

GENERAL FEATURES.

This province, extending from the southern base of the mountains 120 miles southwestward to the limit of the map at the sixty-sixth parallel, lies mainly in the northwestern part of the large basin of the Koyukuk, which forms the northwestern part of the Yukon Basin.^a It consists mainly of a rolling or hilly country of known and supposed Mesozoic rocks, whose hills rise to elevations of from 1,000 to 3,000 feet, while the main valley floors lie at approximately 600 feet.

The general accordance in height of the hills and ridges of this province at two different levels strongly suggests that the present topography has been carved from two



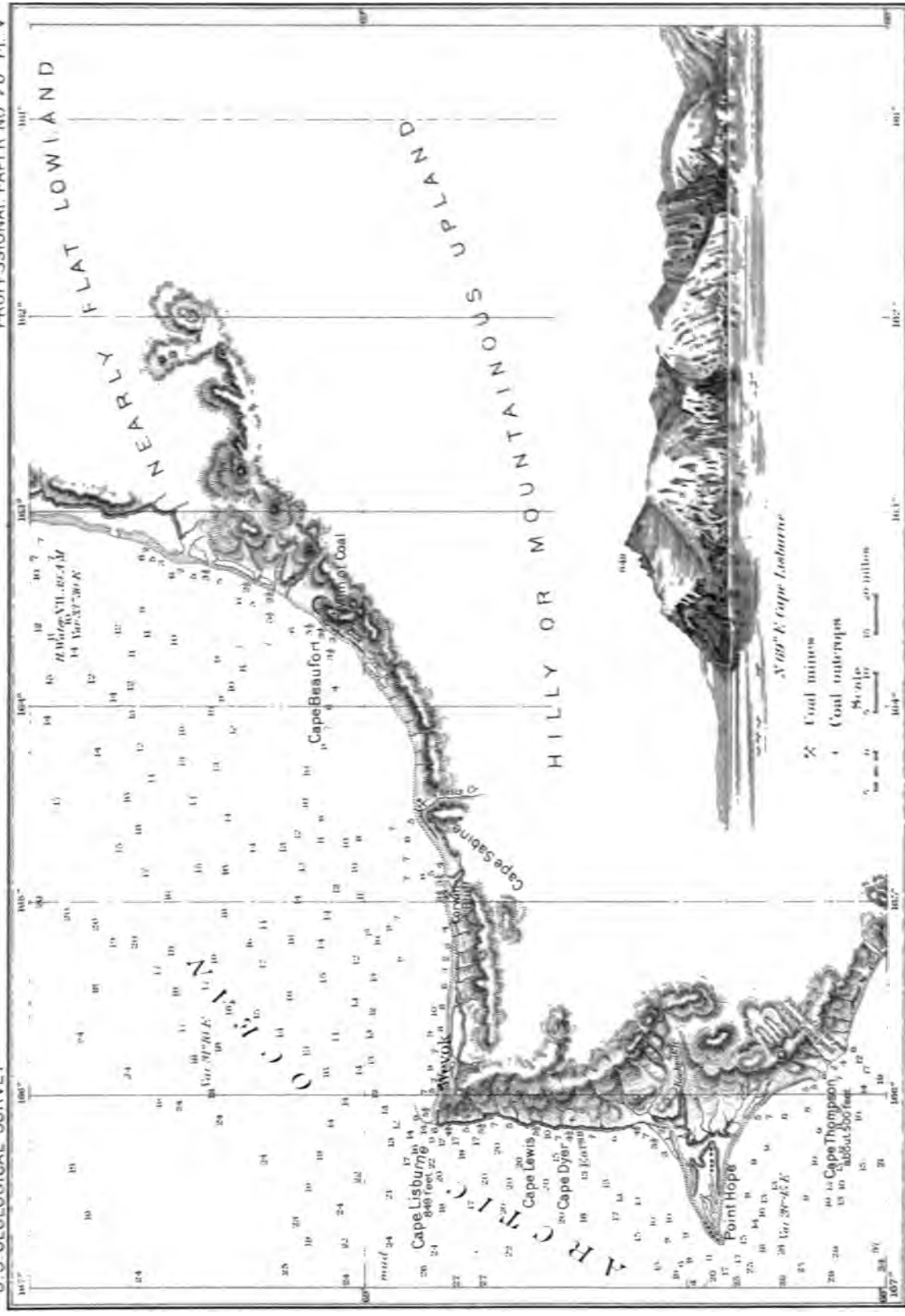
FIG. 2.—Diagrammatic profile showing relations of Endicott, Yukon, and Koyukuk plateaus.

former plateau features (see fig. 2). Though, for need of further investigation, this question can not be discussed in detail in this place, it may be noted that of these two features the lower level, at about 1,200 feet, is relatively distinct and well marked, and represents the general elevation of the land mass over the larger part of this portion of the Koyukuk Basin, as may be seen on the map (Pl. II). For it the name Koyukuk Plateau is suggested.

The higher level, which also suggests a former plateau now dissected and largely removed by erosion, lies at about 3,000 feet, but it is indefinite. Its best expression occurs along the base of the mountains, where portions of nearly flat-topped ridges, rising gently northward, soon merge into the foothills of the mountains, while to the south they become lost in irregular ridges and hills, descending to the lower or Koyukuk Plateau. This higher level, where formerly observed, at an elevation of from 2,500 to 3,000 feet, to the east, on Chandler and upper Koyukuk rivers, near the sixty-seventh parallel, was supposed to represent the Yukon Plateau,^b but

^aFor a more complete description of the Koyukuk Basin the reader is referred to Preliminary report on a reconnaissance along the Chandler and Koyukuk rivers, Alaska, in 1899: Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 2, 1900, p. 467. See, also, Recent work of the United States Geological Survey: Bull. Am. Geog. Soc., vol. 34, No. 1, Feb., 1902.

^bSchrader, F. C., Preliminary report on a reconnaissance along the Chandler and Koyukuk rivers, Alaska, in 1899: Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 2, 1900, p. 99.



SKETCH MAP OF CAPE LISBURNE REGION
SHOWING COAST LINE AND LOCALITIES OF COAL DEPOSITS



owing to its feeble development to the northwest and to its remoteness from the known Yukon Plateau feature, the present work, though it yields supporting evidence, has not gone far toward confirming this supposition.

DRAINAGE.

The drainage of this province, which is separated from that of the Arctic slope by the above-described mountain range, is southwestward. The master stream is the Koyukuk, which flows into the Yukon. It is navigable for some distance above Bettles, to near the sixty-seventh parallel. Next in size are John and Alatna rivers, tributaries to the Koyukuk from the north, and South Fork from the south, all of which at high water may be ascended by steamboat for 20 to 30 miles above their mouths. Other prominent tributaries are Hokotena River or Wild Creek and Alashuk River from the north and Kanuti River from the south.

All the above streams, as shown on the map, meander over their broad, flat valley floors, which vary from 1 to 10 or more miles in width. On the lower and middle portion of the Koyukuk the flats attain a very much greater width, being, in a measure, comparable with the Yukon Flats. To this portion the name Koyukuk Flats^a has been applied.

ARCTIC SLOPE PROVINCE.

This province, beginning at the north base of the Endicott Mountains, in latitude $68^{\circ} 25'$, extends 160 miles northward to the Arctic coast. From the Anaktuvuk and Colville it appears to extend eastward to the foot of the mountains, 70 to 80 miles distant, while on the west it is inferred to probably extend to the Arctic coast, between Point Barrow and Cape Lisburne, a distance of about 400 miles. It is mainly with the eastern portion of the province that we shall here have to deal. This portion embraces almost the whole of the Colville Basin, and consists primarily of two distinct features, plateau and coastal plain. For the former feature the name Anaktuvuk Plateau is proposed.

ANAKTUVUK PLATEAU.

Beginning at the north base of the Endicott Range, at an elevation of 2,500 feet, as shown on the left in Pl. IV, *A*, this gently rolling plateau or plains country, composed of Mesozoic rocks, extends with gentle slope northward for a distance of 80 miles, to latitude $69^{\circ} 25'$, where, at an elevation of 800 feet, begins the nearly flat coastal plain next to be described. In the Anaktuvuk Valley a still more gentle aspect is given to the topography of the Mesozoic rocks by the glacial drift.

The most prominent features of this plateau are a few low, broad ridges, which lie parallel to or concentric with the curved front of the mountain range, and the shallow drainage valleys (see Pl. IV, *A*), trending north and south. These ridges

^aSchrader, F. C., Preliminary report on a reconnaissance along the Chandler and Koyukuk rivers, Alaska, in 1899: Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 2, 1900, p. 468.

present the concavity of their curve to the north, and, as suggested, appear to owe their origin to a part of the same uplift that formed the more abrupt front of the main range. They seem to be persistent features between the Colville and the head of Chipp (Ikpikpuk) River, where they trend a little north of west. Farther west they presumably merge into the Meade River Mountains, at the head of Meade River, in latitude $69^{\circ} 20'$, and probably continue still farther westward to the Arctic Ocean, where much the same type of topography, also cut in Mesozoic rocks, appears in the region north of Cape Beaufort.

Where traversed by the Survey party, the most pronounced of these ridges occurs about 20 miles north of the mountains. It is low, broad, and somewhat rounded. Its highest points rise only 500 to 600 feet above the general plateau level, or about 1,200 feet above the bed of Anaktuvuk River. A sectional profile of this ridge, sketched from a point a few miles above it, on the Anaktuvuk, is presented in fig. 3.

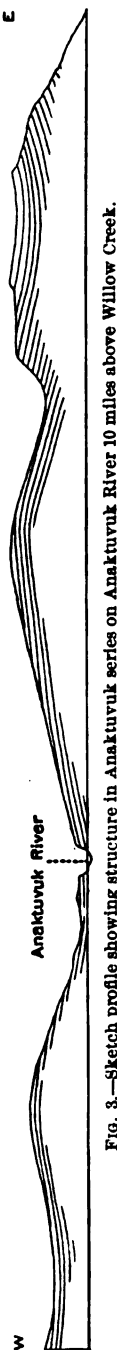
ARCTIC COASTAL PLAIN.

In latitude approximately $69^{\circ} 25'$, at a distance of 80 miles from the mountains, and at an elevation of about 800 feet, the northern edge of the above-described Anaktuvuk Plateau gives way to a nearly flat tundra country or coastal plain, which from this point extends about 80 miles northward to the Arctic coast, and descends in this distance practically to sea level, with slope so gentle as to be inappreciable to the naked eye. For this feature, by reason of its geographic position, the name Arctic Coastal Plain is here proposed. This plain is practically constructional. The flat surface of its large interstream areas is dotted here and there by extremely shallow ponds and lakelets, which in most instances are without outlet and present no suggestion of the development of any system of drainage. Along the west side of the Colville the eroded edge of this part of the plain forms continuous steep bluffs, which gradually decrease in height northward, from 200 feet at the mouth of the Anaktuvuk to about 80 feet at Ocean Point, 40 miles distant. The few rivers that traverse the plain flow with considerable velocity in its inland portion, but toward the coast they become sluggish.

DRAINAGE.

COLVILLE RIVER.

The drainage of this Arctic slope province is essentially northward, into the Arctic Ocean. The master stream is Colville River. The Colville has a drainage basin of about 30,000 square miles. It rises in the



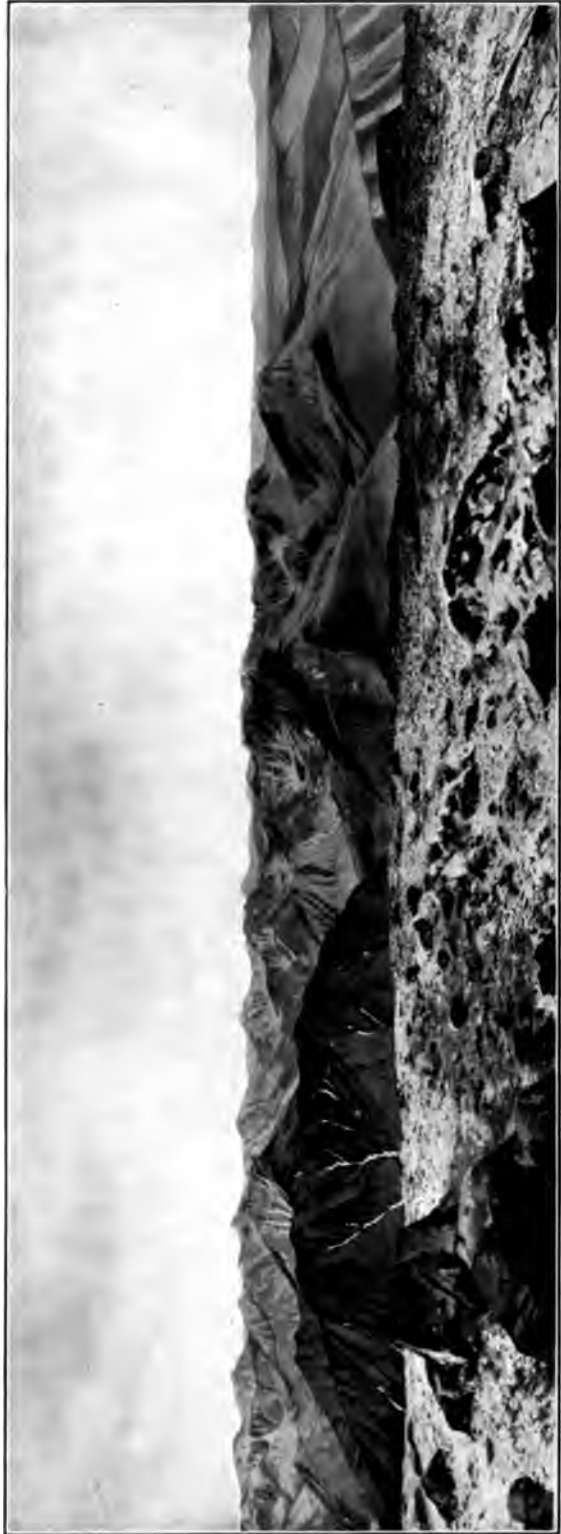


A. TOPOGRAPHY OF JOHN RIVER VALLEY IN ENDICOTT MOUNTAINS.
From near south edge of Fickett series; looking S. 60° E., into Skagit formation.



B. GLACIATED SIDE SLOPES OF JOHN RIVER VALLEY IN ENDICOTT MOUNTAINS.
Looking N. 15° E.





BISECTED VIEW OF ENDICOTT PLATEAU AND ENDICOTT MOUNTAINS CARVED FROM IT, PRINCIPALLY IN FICKETT SERIES.
From Fork Peak, at 6,000 feet, near head of John River. A, Looking east; B, looking south.

northern part of the Endicott Mountains, near the sixty-eighth parallel and the one hundred and fifty-third meridian, whence it soon makes a large detour to the west and back, and then, in flowing northward to the ocean, traverses both the Anaktuvuk Plateau and the coastal plain. Practically all its tributaries of any importance are received from the right, or southeast. The chief of these—the Ninuluk, Anaktuvuk, and Itvelik—head in the mountains.

In the inland part of the coastal plain, at the mouth of the Anaktuvuk, as shown by continuous bluffs, the Colville has sunk its bed to a depth of 200 feet (see Pl. VIII), and at Ocean Point, 40 miles farther north, where it permanently leaves the bluffs, to a depth of 80 feet below the surface of the plain. In this downcutting, from a point above the mouth of the Anaktuvuk to the coast, the Colville has migrated laterally westward, into the terranes composing the plain, to such an extent that, while its left or western shore is for the most part lined by steep-faced bluffs, rising from 80 to 200 feet above the stream to the level of the plain, into which it is still cutting, on the right or east it is bordered by an expansive waste of low abandoned flats, laid waste by the river, for which the name Colville Flats is proposed.

These flats occupy a triangular area of probably 2,000 square miles, extending from the mouth of the Anaktuvuk as the apex northeastward to the coast, where, including the Colville delta, they attain a maximum width of probably 50 or 60 miles. They are dotted by numerous shallow ponds and lakelets. The monotony of their almost dead level is occasionally relieved by low mounds of gravel, rising 10 to 40 feet above the surface. In fact, from near the mouth of the Anaktuvuk the Colville seems formerly to have flowed more directly northeastward through the area now occupied by the flats and entered the ocean through Gwydyr Bay, from 30 to 40 miles east of its present delta, if not Prudhoe Bay, still farther eastward, at the base of Return Reef, as shown by the broken lines on the map forming Pl. III.

At the head of the Colville delta, where the edges of these flats form the stream banks, their surface lies about 10 feet above the river. Here they are composed chiefly of dark mud, muck, and ground ice, while at certain localities farther inland the banks give way to stretches of gravel beach sloping gently to the water's edge.

The Colville delta at present has a radius of about 15 miles and a width across the front of about 20 miles. It is composed of low islands, which coastward gradually pass into marshes, mud flats, bars, and expansive shallows, which are continuous with the very gradually deepening sea floor. Near the head of the delta sand dunes have been formed on some of the islands to a height of 60 or more feet. As the "Pelly Mountains" of Dease and Simpson, represented on their map to the west of the Colville delta, do not exist, it seems probable that the features which these men mistook for mountains were merely low sand dunes, similar to those above referred

to. This view is strengthened by the fact that under certain conditions of light along the coast low objects become, by refraction, enormously exaggerated in vertical scale.

Colville River has formerly been described as having four mouths, but it probably has five or six. The westernmost is said to be shallow, but the second from the west is navigable and is used by the natives in ascending and descending the river on the west. Whether any of these channels will admit river steamboats was not learned. If so, it must be the right or most easterly channel, which seems to be the main one. Once across the delta, judging from its gradient and volume, the river can probably be ascended by steamboat for a distance of 150 or more miles above its mouth. McClure, in crossing Harrison Bay in 1850, found the freshening influence of the Colville to extend 12 to 14 miles seaward, the surface of the water being of a dirty mud color and scarcely salt.

ANAKTUVUK RIVER.

Next to the Colville, the principal stream of this province is Anaktuvuk River, the large southeast tributary of the Colville, which, rising in the northern part of the mountains, flows almost directly northward across the Anaktuvuk Plateau and joins the Colville at the inland edge of the coastal plain. At about 30 miles from the mountains the Anaktuvuk is joined on the east by Willow Creek, a stream equal to itself in size.

Above Willow Creek, owing to the swiftness of the current and frequent riffles formed by large boulders that beset the bed of the stream, the Anaktuvuk can hardly be regarded as navigable at ordinary water for canoe or rowboat. In the upper section of the river, the valley, as shown in Pl. IV, *A*, is shallow and open, with no bluffs or banks to speak of. The tundra extends almost to the water's edge.

Below Willow Creek the floor of the valley consists of a gravel- or boulder-covered flat, a mile or more in width, along the edges of which the gentle, moss-covered side slopes are occasionally interrupted by low bluffs rising from 20 to 100 feet above the river. Willow Creek and Nanushuk River both seem to head in the mountains to the southeast of the edge of the plateau, while Tuluga River, on the west, apparently takes its rise on the plateau, near its middle part.

COAST LINE.

From Colville River to Point Barrow.—The northern Arctic coast of Alaska, from the mouth of the Mackenzie to Point Barrow, trends a little north of west. It is low and flat, the actual shore line being formed by a low shelving beach (Pl. IX, *A*), whose seaward extension forms the shallow sea floor. From east of the Colville westward to Point Barrow the surface of the tundra often descends to or within a few feet of tide level, so that the same gentle slope seems to be continued in the very



U. S. GEOLOGICAL SURVEY



A



C

BISECTED VIEW OF COLVILLE RIVER I

A and B, Look



B



N

D.

Y COASTAL PLAIN OF COLVILLE SERIES.
looking northwest.



gradually deepening sea floor. The greatest height of the bluffs is about 30 feet. The drainage ways are consequently broad and very shallow.

The coast line is comparatively regular, though not nearly so uniform as represented by the early explorers Dease and Simpson. It is more or less broadly sinuous or wavy, its first striking uniformity being broken by occasional lagoons, shallow embayments, and inlets; but in comparison with the coast of southern Alaska, for example, it can not be called indented. Some of the embayments mark the mouths of rivers, but most of the larger ones seem to occur independent of inland drainage. The deepest, and perhaps the only one to which the term indentation will strictly apply, is Dease Inlet, at the head of which is situated Admiralty Bay, which receives the Chipp (Ikpikpuk) River. The principal streams entering the sea between the Colville and Point Barrow are Garry, Smith, Sinclair, Chipp (Ikpikpuk), and Meade rivers. These rivers, however, could not all be visited by the party in its rapid progress along the coast. So far as known, they in general have wide mud-flat deltas, much the same as the Colville, which pass seaward into shallows, merging with the shallow coastal shelf of the sea.

It is judged that the coastal shelf extends far offshore, with a slope probably even less than that of the nearly level subaerial coastal plain. Captain McClure found the soundings so exceedingly regular that during the foggiest weather the vessel could stand inshore with the most perfect confidence in $3\frac{1}{2}$ fathoms of water, and the *Investigator* is reported to have passed the mouth of the Colville 40 miles out to sea in $3\frac{1}{2}$ fathoms. The range of tides on this portion of the Arctic coast is very small, being only 2 or 3 feet.

Point Barrow, the northern extremity of this low coast and of the American continent, is a low spit of gravel and sand, projecting to the northeast, in latitude $71^{\circ} 23'$, longitude $156^{\circ} 40'$. It is 4 miles in length and about one-fourth mile in width, but expands at the end, where it rises to a height of 16 feet and sends out a long, narrow ridge, which extends east-southeastward for a distance of more than 2 miles. This ridge finally gives way to a line of sandy islets, inclosing a shallow body of water of considerable extent, named Elson Bay, after the discoverer of Point Barrow.

From Point Barrow to Cape Lisburne and beyond.—The trend of the coast line changes from northwest to southwest at Point Barrow and thence extends about 300 miles southwestward to Cape Lisburne. It continues comparatively straight and regular, but it is not so low as on the north. It soon loses the almost featureless edge which is characteristic of the flat coastal plain on the north, and gradually comes to exhibit low, but seldom rock-faced, bluffs, rising 30 or 40, rarely 70, feet above tide. Back from the shore a very gently rolling surface rises very gradually toward the interior, but no highlands or mountains can be seen. Seaward the bluffs overlook immense stretches of brackish lagoons, from one to several miles in width, which

rather persistently line the coast. These lagoons are screened from the force of the open sea by broad wave-built barrier reefs and beaches of sand and gravel, through which occasional narrow channels, cut by the ebb and flow of the tide, connect with the outer water. On portions of the coast not thus protected, during a northwest gale the mouths of the smaller valleys become entirely clogged and the streams themselves are then dammed back by the broad beach barriers thrown up by the violent surf. In the rear of these barriers the lower reaches of the valleys then become temporarily converted into broad lakelets, whose surface may rise 5 or 6 feet above normal tide level; but with the abatement of the storm a new drainage channel is opened through the beach and the lake disappears.

Near Cape Beaufort, latitude $69^{\circ} 15'$, the above-described low topographic relief gives way to a range of hills or low, rolling mountains, which, sweeping a little south of west, appear at the coast with an elevation of 800 to 1,000 feet. They are supposed by the writer to represent the westward continuation of the Meade River Mountains, already referred to. Farther southwest they seem to merge into the somewhat more pronounced and rugged mountains of Cape Lisburne, which, as noted, are supposed to represent the westward continuation of the northern axis of the Endicott Range, noted at the head of the Anaktuvuk, in longitude 152° .

Here these mountains, as noted, terminate at the coast in abrupt sea cliffs, forming the bold promontory of Cape Lisburne, which rises to a height of 850 feet above tide. From Cape Lisburne the mountains, with decreased altitudes, continue southwestward in several successive parallel ridges, trending at about right angles to the coast. The shore line, however, is here less abrupt, as shown in fig. 1 (p. 40).

About 30 miles south of Cape Lisburne the shore extends out nearly 15 miles to the west in an immense tongue of low, sandy land, known as Point Hope, which is backed by bluffs at its inland end.

From Point Hope southeastward to Cape Krusenstern, at the entrance to Kotzebue Sound, the coast is reported to be low and somewhat rocky, with intervals of lagoons and wave-built barrier reefs, somewhat resembling those already described; but in latitude $67^{\circ} 35'$, opposite the great bend of the Noatak, low mountains, known as the Mulgrave Hills, again approach the coast.

The streams entering the coast on the northwest are nearly all short. The principal, beginning at the north, are Kee, Kukpowruk, Pitmegea, and Kukpuk rivers.

GEOLOGY.

GEOLOGIC MAP AND SECTIONS.

The results of the very incomplete observations concerning the distribution of the geologic formations here treated of are represented on the accompanying geologic map (Pl. III), the colored portion of which, comprising an area of about 27,000 square miles, lies mainly between the one hundred and fiftieth and one



A. ARCTIC COAST AND EDGE OF MOSS-COVERED ARCTIC COASTAL PLAIN.
From west of Colville River; looking S. 45° E.



B. SKAGIT LIMESTONE ON JOHN RIVER IN ENDICOTT MOUNTAINS.
Looking S. 65° E.

hundred and fifty-fifth degrees of longitude. As the line of traverse extends in a north-south direction across the trend of the terranes, which has been found to be relatively constant, especially in the mountains, the boundaries delimiting the various formations on the north and on the south, along the line of the section, are approximately correct and in some instances are well defined. In an east-west direction some liberties have been taken in making such broad generalizations as seemed permissible from the regularity of the terranes in the mountains and their relations and lithologic resemblance to those previously mapped to the east.

The boundaries of the post-Paleozoic formations of the Arctic slope, approximately determined on paleontologic and lithologic evidence along the route of traverse, have been extended eastward and westward on topographic evidence and on observations and collections made by the writer in returning southward along the coast from Point Barrow to Cape Lisburne.

At the north base of the mountains, where the profile, descending from the mountains, passes from the upturned Devonian onto Pleistocene till, which farther north is found resting on Lower Cretaceous, a belt several miles wide has been left blank, in view of the possible occurrence of Carboniferous and Lower Mesozoic rocks between the Devonian and the Cretaceous; and similar contact gaps have been left in other parts of the section. On topographic grounds, however, it seems probable that the Mesozoic and Carboniferous formations are absent at the above point on the Anaktuvuk, having been removed by erosion, and that the inland edge of the Lower Cretaceous or Jura-Cretaceous may rest directly on the Devonian, as indicated in fig. 4. Areas away from the route traversed, where the geology is unknown, are also left blank; while, on the other hand, general geologic information and the probable occurrence of certain formations are represented by notes printed in red. East of the geologically colored portion of the map the notes applying to the region lying north of the Arctic Circle are based on the work of the writer in a previous year,^a while those to the south of the Circle, on the west, and along Alatna and Kowak rivers in the region of the sixty-seventh parallel are by Mr. W. C. Mendenhall, geologist in charge of the Kowak expedition, whose work^b has just been published.



^aSchrader, F. C., Reconnaissance along the Chandlar and Koyukuk rivers, Alaska: Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 2, 1900, p. 448.

^bMendenhall, W. C., Reconnaissance from Fort Hamlin to Kotzebue Sound, Alaska: Prof. Paper U. S. Geol. Survey No. 10, 1902.

A profile and geologic section appearing on Pl. III, drawn on the same scale as the map, illustrate the structural features and relations of the various rock formations. It extends from the southern edge of the map at A (Pl. III) to the foot of the Colville delta and the Arctic coast at J. In order to show the structure in the Tertiary coastal plain and to represent the flats and delta near sea level at the north, the scale of the section has been vertically exaggerated 5:1 as compared with the horizontal scale, and in order to represent more accurately the relations of the rocks as actually observed the section follows the somewhat zigzag line of traverse. Where it traverses the rocks diagonally, as in the northern edge of the Fickett series, compensation has been made therefor by reducing the dips of the rocks in the section. As the line of traverse follows the valleys, where the topography has been reduced by erosion, the profile rarely rises to the normal height of the adjacent land mass. Consequently the peneplain feature of the Endicott Mountain summits is not expressed by the profile. From studies thus far made of the section it promises to be of far-reaching importance, not only in deciphering the geology of Alaska, but also in making correlations with Asiatic stratigraphy.

Near the northern edge of the range, as shown on the map, the section traverses the mountains to the east of the Anaktuvuk Valley, but as the rocks have here been disturbed by folding and faulting, a supplementary short profile section (fig. 4), showing the rocks as they appear on the west side of the valley, has been introduced. It extends from the Lower Carboniferous at Contact Creek on John River a distance of about 25 miles northeastward across the Devonian, along the north side of Anaktuvuk Pass, to the Cretaceous of the Anaktuvuk Plateau on the west of Anaktuvuk River. The base of this section represents approximately the elevation of the floor of the Anaktuvuk Valley and that of the pass, which is about 2,500 feet. The mountains rise to about 5,500 feet. Besides the faulting shown between the Devonian and the Lower Carboniferous on the south, and in the Devonian itself toward the north, the section supposes the Lower Cretaceous to be resting unconformably on the upturned and eroded Devonian.

OUTLINE OF GEOLOGIC HISTORY.

The rocks composing the section here considered, extending geographically from the sixty-sixth parallel to the Arctic coast, a distance of nearly 400 miles, comprise representatives of most of the geologic ages ranging from Silurian to Recent, as shown in the accompanying table.

TABLE OF GEOLOGIC FORMATIONS.

<i>Sedimentary rocks.</i>		
Pleistocene		Recent stream gravels, dune sands, mud flats, silts, beach gravels, Gubik sand, ground ice, and glacial drift.
Tertiary (Colville series)	Pliocene	Nearly horizontally stratified, fine-grained calcareous silts.
	Oligocene	Sand, clay, shale, soft sandstone and limestone with lignites, hard ferruginous sandstone, and conglomerate.
Mesozoic	Upper Cretaceous (Nanushuk series).	Soft sandstone, limestone, shale, and coal.
	Cretaceous (?) (Bergman series).	Sandstone, slate, grit, conglomerate, and coal.
	Lower Cretaceous (Koyukuk series).	Impure limestone, sandstone, slate, and associated igneous rocks.
	Lower Cretaceous (Anaktuvuk series).	Principally impure sandstone or arkose, with some conglomerate or grit.
	Jura-Cretaceous (Corwin series).	Sandstone, impure limestone, shale, and bituminous coal.
	Lower Carboniferous (Fickett series).	Phyllites, slate, limestone, sandstone, quartzite, grit, and conglomerate.
Paleozoic	Devonian (Lisburne formation).	Limestone and shale.
	Silurian (probably) (Totsen series).	Mica-schists and quartz-mica-schists.
	Upper Silurian (Skajit formation).	Schistose and micaceous limestone.
	Pre-Devonian (probably) (Stuver series).	Conglomerate, quartzite, slate, and shale.

Igneous rocks.

Post-Silurian dike (?) rocks, associated with the Skajit formation.
Cretaceous and post-Cretaceous dike rocks, associated with the Koyukuk series.

The oldest rocks encountered in the field consist of several metamorphic series. They are principally of sedimentary origin, and have acquired their present character largely by processes of mountain building, which, broadly speaking, seem to have been in progress intermittently since Middle Paleozoic time, and are probably still going on.

These metamorphic rocks are exposed only in the mountainous portion of the field. The different series are here designated by the names Skajit, Totsen, Stuver, Lisburne, and Fickett. Though the Totsen series is mainly sedimentary, it includes also some greenstone-schists of igneous origin, which appear to be old basaltic flows, but may be intrusives.

With probably a single exception, igneous rocks were not observed with any of the other metamorphic series. This exception was on John River, near the middle of the Skajit formation, at a point about midway between camps of June 23 and June 24. Here, in the face of the upper part of a cliff which rises steeply to a height of 2,000 feet above the edge of the stream, as seen from the opposite side of the river, looking northeast, but which, owing to difficulty of access and lack of time was not visited, the limestone is cut by what appears to be two classes of dikes (but

which may possibly be veins), one dark and the other light. These supposed dikes are thin, and they are younger than the schistosity of the country rock. The dark ones are the older, and cut the rock for the most part obliquely to the schistosity or bedding, which they slightly exceed in dip, the dip being to the north, at an angle of about 45° . The light dikes cut the rocks at nearly right angles to the dark dikes and dip south at an angle of about 80° , and seem to follow fault planes or fissures that were manifestly produced subsequent to the intrusion of the dark dikes.

The above division of the rocks is based largely on paleontologic evidence. But the Totson series, in which no fossils were found, is assigned to a low place in the geologic scale by reason of its crystalline character or high degree of metamorphism and the known relatively low stratigraphic position in which similar rocks occur in adjacent regions. The Stuver series, in which likewise no fossils were found, is regarded as among the older rocks by reason of its field relations to the overlying Devonian.

After the deposition of the oldest Paleozoic sediments occurring in the present southern axis of the main range, this part of the region seems to have been uplifted and subjected to dynamic action and metamorphism, following which a portion of the field probably remained above sea during the whole or a part of the period in which the Devonian sediments were being laid down in the region now occupied by the northern axis. During this period of deposition, which possibly extended into early Mesozoic, the later Paleozoic sediments, including apparently the Carboniferous, seem to have been deposited unconformably against the older rocks of the southern axis. This period was followed by stress, uplift, and the exertion of mountain-building forces, resulting in folding, metamorphism, and deformation of the strata.

Then followed a long pause, during which the reduction of the land area by subaerial erosion nearly to sea level gave rise to the peneplain or formerly nearly level surface of the Endicott Plateau. This base-leveling was, in turn, followed by elevation of the region, whence upward movement seems to have continued more or less intermittently down to the present time. Uplift was accompanied by vigorous dissection of the plateau, from which the Endicott Mountains, as we find them to-day, seem manifestly to have been carved.

Contemporaneous with this uplift and dissection the sediments eroded from the range were borne to the sea and deposited as new terranes on both the north and the south side of the mountains. These later deposits range in age from Middle Mesozoic to recent. Though throughout this period the Endicott Plateau seems to have stood above the sea, the region was subjected to somewhat pronounced changes of level and disturbance, as is evidenced by deformation and unconformities extending from Middle Mesozoic to Pleistocene.

The later of these disturbances is that suggested by the vigorous cutting of the left or west bank of Colville River into high bluffs (Pl. VIII), while the east bank consists only of the edge of an expansive waste of low flats abandoned by the river in its lateral migration during its down cutting. This shifting or lateral migration of the river was evidently brought about by a tilt, which is apparently more than a local disturbance, for other examples indicate that there has been a general tilt throughout northern Alaska, which has caused and is still causing the larger rivers, notably the Yukon, the Porcupine, the Koyukuk, the Kowak, the Colville, and the Anaktuvuk, to cut their western banks.^a This differential upward movement of the region probably extends eastward to the international boundary or farther, and, judging from the lateral migration of the Colville into the Pleistocene as well as the Tertiary and Mesozoic terranes, it took place, in part at least, in the Pleistocene, and is probably still in progress.

During Lower Cretaceous time, deposition on the south of the range, in what is now the Koyukuk Basin, was apparently accompanied by igneous extrusions and followed by intrusions, which latter continued into post-Cretaceous time,^b while the range itself and the Arctic slope, so far as observed along the route of traverse, are relatively free from igneous rocks. It was supposed by the writer that the northeast-southwest trend of the Koyukuk Valley, from the Yukon to the sixty-eighth parallel, probably represented in a general way a line of weakness in the earth's crust, along which igneous phenomena are especially manifest. More recent work, however, along Kanuti and Kowak^c rivers and on Kotzebue Sound, shows that the igneous rocks are distributed over a much wider area in this northern country than in that occupied by the Koyukuk Valley.

SEDIMENTARY ROCK FORMATIONS.

PALEOZOIC ROCKS.

STRUCTURE.

Beginning with apparently the oldest, the several formations or rock series will be briefly described. As the field is new and the investigations have not been detailed, the formation names introduced are proposed provisionally.

To afford a more comprehensive view of the relations of the several series and to avoid repetition in referring to them individually, it will be well to note at the outset some features of structure which are common to nearly all the Paleozoic rocks, and which apply to the range as a whole, namely, that the series all strike approximately

^aThe fact that the Yukon in the lower part of its course is cutting its right or western bank has been noted by Dall, Russell, Spurr, and others.

^bSchrader, F. C., Reconnaissance along the Chandlar and Koyukuk rivers, Alaska: Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 2, 1900, p. 481.

^cMendenhall, W. C., Reconnaissance from Fort Hamlin to Kotzebue Sound, Alaska: Prof. Paper, U. S. Geol. Survey, No. 10, 1902, map, p. 30.

east and west, parallel with the trend of the range. They are nearly all traversed by the dominant jointing of the range, which cuts the rocks in a direction about northeast-southwest, with dip nearly vertical or inclined steeply to the northwest, at angles of 75° to 80° . There are also usually one or more sets of secondary jointing or minor structure, trending in general northwest-southeast, sometimes approximately at right angles to the major jointing.

The above statement of the structures affecting the Paleozoics in the range applies also in a limited way to the upland Mesozoics on either side.

With the exception of the greenstone-schists occurring in the Totsen series, the Paleozoics of the range, as well as the younger formations of the Arctic slope, are all sedimentary, and, so far as observed, are relatively if not wholly free from association with igneous rocks of any kind.

SKAJIT^a FORMATION (UPPER SILURIAN).

Character and occurrence.—The Endicott Range, as noted, has two distinct axes, of which the southern seems to be composed of the older rocks (see Pl. III), those of the Skajit formation and the Totsen series, the former playing the principal part.

The rocks of the Skajit formation (Pl. IX, *B*) consist of heavy-bedded crystalline limestone and mica-schist. Weathered surfaces, parallel with the bedding and planes of movement and crushing, present a silvery sheen, due to the presence of mica, while some layers grade wholly into mica-schist. On a fresh fracture surface the limestone is found to be highly crystalline, generally fine or medium grained, and of impure white or bluish-gray color, the latter apparently denoting the more dolomitic phases of the rock. It weathers to a dirty gray or light brown, sometimes tinged with red.

The formation occurs in the southern part of the Endicott Mountains, where, in latitude approximately $67^{\circ} 30'$, it occupies a belt that is from 15 to 20 miles wide, in which the mountains rise to an elevation of more than 5,500 feet above sea level, the rocks forming some of the highest peaks and most rugged topography of the southern axis of the range. Judging from the attitude or prevailing dip of the rocks and their extent measured across the strike, the formation probably has a thickness of at least 4,000 feet.

Structure.—The Skajit formation has a nearly east-west strike, parallel with the general direction of the mountains; but about 20 miles west of John River this trend changes to north of west. The structure in general indicates a broad anticlinorium whose middle part is occupied by a broad, shallow syncline. In general the dips are gentle, as shown in Pl. IX, *B* and Pl. X, *A*. The latter shows the

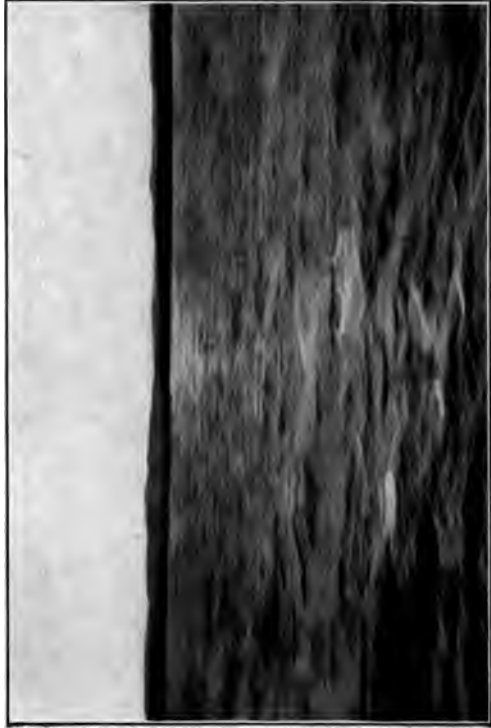
^aThe term Skajit is of native origin, and is taken from a group of rugged mountains occurring within the area of the formation to the east of John River.



A. NORTH EDGE OF SKAGIT LIMESTONE, DIPPING NORTH, ON JOHN RIVER, IN ENDICOTT MOUNTAINS. LOOKING EAST.



B. LISBURNE LIMESTONE AND GROUND MORaine, FROM CACHE LAKE NEAR ANAKTUVUK PASS, IN ENDICOTT MOUNTAINS. LOOKING NORTHWEST.



C. CAPE SABINE AND UNDULATING PLATEAU. LOOKING SOUTH.



D. CAPE HALKETT, SHOWING GROUND ICE TERRANE RISING 30 FEET ABOVE TIDE.

formation as it disappears to the north unconformably under the Fickett series. In some localities, however, the faulting and folding have been intense.

Like the other Paleozoic rocks of the range, the Skajit formation is cut diagonally by the dominant northeast-southwest jointing, which divides the rocks into nearly vertical sheets varying from less than 1 to more than 10 feet in thickness, and by the secondary jointing sometimes at nearly right angles to this direction.

The joint planes are usually nearly vertical or have a steep westerly dip, and are sometimes locally followed by veins or veinlets of calcite and some quartz, carrying occasionally a little galena or iron pyrites and copper. Prospectors report that galena, probably of economic value, occurs on Wild Creek, 25 miles east of our route, in a wide "ledge" in limestone probably belonging to the Skajit formation.

Cleavage was also noted in a few instances, but none so pronounced or so well developed as that observed in similar rocks in the area to the east, at the head of Chandlar River.

Age.—The Skajit formation, as seen in the geologic section, probably represents the oldest or next to the oldest rocks in the field. It is the principal formation forming the southern axis of the Endicott Range, of which it seems to be the lowest terrane exposed. It is unconformably below the Fickett series on the north, and apparently bears similar relation to the Totsen series on the south, where, as shown in the geologic section on Pl. III, the probable unconformity is indicated by the beds of the Totsen series lying at a steeper angle than those of the Skajit formation, as well as by an abrupt change in the character of the sediments along the zone of contact. Similarly, on the north, where the heavy-bedded limestone of the Skajit formation finally disappears with a northerly dip, it is met by the overlying slates and schists of the Fickett series dipping south (section on Pl. III and Pl. X, A).

Though the limestone, as noted, is much altered by metamorphism, it contains faunal remains, some of which were collected in place on John River. While most of these forms are too greatly altered for determination, a single specimen has been identified by Mr. Schuchert as "having the ventral valve of a brachipod of the order of *Meristina* and *Meristella*, and also resembling a transverse *Seminula*. This kind of shell indicates that the rock can not be older than Upper Silurian and not younger than Lower Carboniferous."

On this evidence, and because the rock is much more disturbed and metamorphosed than the limestone of the Lisburne formation, in which Devonian fossils have been found in the northern axis of the range, the Skajit formation is provisionally referred to the Upper Silurian. This, if the inference be correct, places it among the oldest known fossil-bearing formations of northern Alaska. Late Upper Silurian forms have been found in the Glacier Bay limestone in southeastern Alaska.^a Ordo-

^aBrooks, A. H., Preliminary report on the Ketchikan mining district, Alaska: Prof. Paper U. S. Geol. Survey No. 1, 1902, pp. 19-20.

vician fossils have been found by the Survey party on Seward Peninsula,^a and Lower Silurian forms^b were also found by Mr. A. J. Collier during the season of 1901 in the same region.

Silurian fossils are also reported to have been collected^c by Buckland, Dall, and others at Cape Lisburne and the adjacent Cape Thompson, but, so far as known to the writer, no section or description of the rocks is given. In Dana's *Manual of Geology* it is stated that species of *Lithostrotion* have been found in the Arctic coast lands between Cape Lisburne and Kotzebue Sound. Lower Silurian fossils were collected by Mr. Schuchert on the northeast coast of the continent, in Baffin Land.

Correlation.—From the schistose, crystalline, and micaceous character of the Skajit formation and its resemblance to similar rocks of the Bettles series,^d it is here provisionally correlated with the schistose phase of the Bettles series occurring at the head of Chandlar River, with which subsequent detailed work in the intervening region may connect it. It seems probable that the limestone reported by prospectors to occur in the gold placer district in the Koyukuk, between the Skajit formation on John River and that on the Chandlar, represents this connection. In an earlier report^e the Bettles series was tentatively correlated with the Fortymile series of Spurr. If, however, the Skajit formation proves to be Upper Silurian and its correlation with the Bettles series is correct, the previous correlation of the Bettles limestone to the north of the Yukon with the pre-Silurian Fortymile series to the south, in the Fortymile district, may have to be abandoned.

TOTSEN SERIES^f (SILURIAN).

Character and occurrence.—This series of rocks occupies a belt about 12 miles wide on John River. It lies south of the Skajit formation, upon which the Totsen rocks seem to rest unconformably, while they in turn are unconformably overlain by the Bergman series on the south. The rocks are mainly mica-schists and quartz-mica-schists, in both of which the essential minerals are biotite and quartz. There is also some much-altered greenstone or amphibole-schist. Locally the mica-schist becomes graphitic, graphite bodies one-eighth inch in diameter being noted, and in some cases

^aBrooks, A. H.; Richardson, G. B.; Collier, A. J., and Mendenhall, W. C., Reconnaissances in the Cape Nome and Norton Bay Regions, Alaska: Special publication U. S. Geol. Survey, 1901.

^bGraptolites were found by Messrs. A. H. Brooks and L. M. Prindle along the northern base of the Alaskan Range in the summer of 1902.

^cCorrelation papers, Neocene: Bull. U. S. Geol. Survey No. 84, pp. 248-249.

^dSchrader, F. C., Reconnaissance along the Chandlar and Koyukuk rivers, Alaska: Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 2, 1900.

^eIbid.

^fThe name Totsen is derived from the term Totsenbetna—formerly applied by the natives to Wild Creek—by dropping the final syllables, which signify river. On the map accompanying the writer's report on the expedition of 1899, and on that in Mendenhall's report of 1902 (Prof. Paper U. S. Geol. Survey No. 10), this name was erroneously applied to the stream which is now called John River, but which Allen designated Fickett's River. The word was spelled Totsen-bitna by Allen. It is said to mean *lune*, the waterfowl.

the rock carries much secondary quartz, both in small veins and in lenticular bodies. Some iron pyrite is also present, which on oxidation gives a reddish-brown color to the rock. The quartz veins tend to follow the schistosity and are often locally contorted and twisted. Some carry irregular veinlets or stringers of epidote.

The series is believed to be essentially of sedimentary origin, but the sedimentation seems to have been accompanied by basaltic flows, which were later sheared with the sedimentary beds, giving rise to amphibolite-schist, of which the most prominent strip, having an apparent width of several miles, occurs near the southern part of the belt occupied by the series. Here the rock, judging from the bent and crushed remnants of feldspar and augite shown under the microscope, is plainly of igneous origin. Though on account of faulting and folding there is doubtless some duplication of the rocks in the Totsen series, its total thickness, judging from the prevailing dip and distance across the strike, is 6,000 to 7,000 feet.

Structure.—The Totsen series, like the older rocks composing the range, trends approximately east and west, and though the series as a whole has been intensely folded, the dip in general is monoclinal, being, so far as observed, southward, at angles of 60 to 80°; but in the northern part of the belt, John River Valley, for a distance of several miles, seems to follow a north-south syncline in the series. The series is traversed by the major northeast jointing of the range, and by a secondary structure at nearly right angles to the major jointing. Cleavage was noted at a few localities, but apparently much of this has been obliterated by disturbance.

Age.—The Totsen series is represented in the geologic section as it appears to occur in the field, namely, above the Skajit series. It thus seems to be younger than the Skajit, but the actual contact between the formations was not seen, as is shown by the gap in the section, and the age relations here indicated can not be demonstrated. Furthermore, while the Totsen series, so far as observed, consists essentially of rocks that seem undoubtedly to belong to the class of older crystalline schists found in Alaska, and can not be correlated with the Fickett series, it should be noted that the observations made were confined to the line of traverse along John River, and the mountains in this part of the field not having been ascended, it is possible that the series may be overlain by or otherwise associated with rocks younger than those described above. The great thickness and probable extent of the Fickett series (to be noted later) to the north of the Skajit formation, makes it not unreasonable to suppose that members of this series may occur on the south side of the Skajit anticlinorium, but this point must be determined by future investigation.

Correlation.—The Totsen series can be correlated in a tentative way, on lithologic grounds, with the Lake quartz-schist^a of Chandler River. It is less evidently of

^aSchrader, F. C., Reconnaissance along the Chandler and Koyukuk rivers, Alaska: Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 2, 1900, p. 474.

sedimentary origin, is more micaceous, and contains much less quartz and more greenstone-schist, of igneous origin. In some localities, however, it very much resembles the more altered phases of the schists to the east of the Koyukuk, in the Slate Creek diggings, which also have been correlated with the Lake quartz-schist of Chandlar River. That the Totsen series extending beneath the younger formations in the Koyukuk Valley may connect with the Slate Creek schists is not improbable, especially since the Bergman series, which occupies a large part of the intervening Koyukuk Valley, seems to rest unconformably upon both.

STUVER SERIES^a (PRE-DEVONIAN).

Character and occurrence.—The next of the older groups of rocks to be considered is the Stuver series, comprising the oldest rocks exposed in the northern portion of the Endicott Range, and apparently forming the core of the north axis. (See section on Pl. III.) The rocks of this series are principally conglomerates, with interbedded layers of quartzite, which toward the top pass into slate and shale. The pebbles composing the conglomerate are practically all siliceous and consist of black, slate-colored, red, green, and bluish flint and milky-white quartz. They range in size from less than an inch in diameter to cobbles, and in a few instances approach boulderets. The cement is siliceous, usually dense, and often contains grains of cryptocrystalline or aphanitic silica, undoubtedly derived from the same parent rock as the pebbles. Great force is required to break the rock with the hammer, and, when broken, the fracture plane is almost invariably found to take a direct course, traversing any pebbles, though perfectly sound, that may lie in its path; in fact, the cementation is so firm as to form of the conglomerate, as a whole, a rock substantially as hard as the hardest flint pebbles that are included in it.

The various colors of the pebbles in the conglomerate make it a very conspicuous rock, so that it is easily recognized where its fragments occur in Pleistocene and intervening formations. These fragments are conspicuous in the Lower Carboniferous rocks succeeding the Lisburne series, and are also represented in the Lower and Upper Cretaceous and in the Tertiary formations. No one of the parent rocks from which the various types of flint pebbles of the Stuver series have been derived has yet been observed. The specimens found in the placer mining gulches to the northeast, on the west side of the Koyukuk, and referred to by the prospectors as "emerald" and "adamant," probably represent flint pebbles derived from the Stuver conglomerate.

The interbedded quartzites in the Stuver series are medium grained and exceptionally hard and siliceous, and are usually of a gray or sometimes a pinkish or reddish color, while the slate is dark.

^aThe name applied to this series is taken from Mount Stuver, situated east of the Anaktuvuk, and named for a member of the party.

Where best exposed between the two limestone areas of the Lisburne formation to the north of the Anaktuvuk, the Stuver series, forming the lower part of the longer limb of an anticline, dips southward at an angle of 30° and passes beneath the limestone of the Lisburne formation. The relation of the two formations immediately at the contact is concealed by talus, but near by begins an exposure which, extending for several miles along the front of the mountains, shows the Lisburne formation dipping southward at an angle of 20° , this dip being but 10° less than that of the Stuver series, which, as it nears the Lisburne formation, gradually decreases southward. From this it is inferred that the Lisburne, where not faulted, probably rests conformably on the Stuver series. If any unconformity exists, it must be very slight.

As shown on the geologic map (Pl. III), the exposure of the Stuver series is limited to a narrow belt, about 5 miles in width, that trends eastward for an unknown distance from the Anaktuvuk Valley, lying between the eroded edges of the Lisburne formation. The series is also supposed to form the bed-rock floor of the Anaktuvuk Valley, beneath the glacial drift, from the north edge of the mountains for a distance of 10 to 12 miles southward, to near the southern edge of the Lisburne formation. There are some small exposures of its upper member beneath the Lisburne along the base of the mountains on both the east and the west side of the valley, while on the south it has probably been brought into contact with the Lower Carboniferous of the Fickett series by faulting. Both here and at the north edge of the series the faulting seems to be normal.

Structure.—To convey a clearer conception of the controlling conditions here, it should be noted that the Stuver series lies in an east-west zone that exhibits the most marked geologic disturbance of the region. Pronounced faulting extends southward into the range for a distance of 15 to 20 miles from its seaward face. This zone extends along the crest of the divide between the Yukon and Arctic coast drainages, in the region at the head of John and Anaktuvuk rivers, and at the southern part of the great crescent formed by the north front of the Endicott Range. The beds in a general way retain the east-west trend noted in the older Skajit and Totsen series. Roughly considered, the uplift, which, judging from sediments in the post-Paleozoic rocks and the unconformable relations of these to the Paleozoic rocks, seems to have been going on since middle or late Paleozoic time, apparently took place in the form of a broad anticline, whose longer limb extends with gentle slope southward and whose shorter limb forms in part the north front of the range. Elevation was accompanied by faulting. The thrust or movement came from the south and apparently produced an overturned fold in the terranes forming the crest of the anticline. The faulting which accompanied this movement broke the beds into several great fault blocks. Erosion followed, which finally brought the Stuver

series to view along the axis of the fold. These are apparently the lowest and oldest rocks exposed in the northern part of the range.

Toward its northern limits and the crest of the fold, as has been noted, the Stuver series dips southward at an angle of 30° . But still nearer its northern limits, practically at the crest of the fold, the beds have been strained, bent downward, and broken, and finally terminate in a well-defined fault scarp, as shown in the section on Pl. III. This scarp trends a little south of east and is visibly pronounced for at least 5 or 6 miles. Along this distance, in the higher part of the mountains, the edges of the broken, hard conglomerate beds forming the scarp are distinctly exposed, generally dipping about 30° S., while at a lower elevation along the face of the scarp the broken-off portions of the same strata have dragged behind along the lower face of the scarp and stand nearly on edge, dipping northward at an angle of 80° . These nearly vertical beds of the Stuver series are met at the contact on the north by the limestone of the Lisburne formation, which dips south at an angle of 75° to 80° . (See section on Pl. III.) The contact of the two formations thus forms a reentrant angle of 25° , opening upward.

The conglomerate of the Stuver series, toward its north edge and along the fault scarp, is intersected by two systems of jointing about equally pronounced. One system trends east and west, with dip vertical; the other nearly north and south, with dip to the east at an angle of 80° . On the top of a low mountain along the edge of the scarp the same hard conglomerate is finely laminated by a well-marked cleavage trending N. 60° E. and dipping northwestward at an angle of 45° .

No estimate can be formed of the thickness of the Stuver series, as its lower limits are unknown. The exposed portion shows a thickness of at least 2,000 feet.

Age.—The Stuver series, from its position underneath the Lisburne series, which on paleontologic evidence is considered to extend to below Middle Devonian, is certainly not younger than Lower Devonian, and it is regarded as probably pre-Devonian.

Correlation.—No other Alaskan rocks with which it may be correlated are known to the writer. Sediments, notably of fine conglomerate, containing materials similar to those forming the conglomerates of the Stuver series, have been noted in the Mission Creek series of the Yukon district; but probably these, like the sediments derived from the Stuver series and now found in the Tertiary and other formations on the Arctic slope, have been many times deposited and reworked since they were derived from their original source.

LISBURNE FORMATION (DEVONIAN).

Character and occurrence.—Lisburne formation is the name here employed to designate the limestone, with some shale, occurring next above the Stuver series at the head of Anaktuvuk River. The name is taken from Cape Lisburne, where

apparently the same formation, consisting of limestone and shale, occurs. On the Anaktuvuk the formation occupies a belt 15 or more miles in width, extending north and south along the valley. Toward the west the belt narrows and appears to soon be delimited on the southwest by the fault scarp of Contact Creek, and, farther west, by the Carboniferous of the Fickett series; while to the east of the Anaktuvuk it seems to widen. The westward extension of the formation may, however, somewhat exceed that represented on the map before it disappears beneath the Carboniferous, for the mountains south of Contact Creek were not ascended.

Where examined along Contact Creek, the north side of the valley for several miles consists of a steep wall, or fault scarp, of the Lisburne limestone, similar to that forming the scarp along the Anaktuvuk Valley on the east; while the rocks directly opposite, on the south side of the valley, less than three-fourths mile distant, are Carboniferous quartzite and conglomerate of the Fickett series. Northwest of this locality, however (as shown in Pl. IV, *B*, a view looking westward from the south edge of a Lisburne fault block near Contact Creek), the Lisburne, still forming the crest of the axis, with an elevation of about 6,500 feet, is less disturbed. The beds on the right, which show a marked increase in shale at the expense of the limestone, dip northward toward the base of the range, while farther west the Lisburne seems gradually to disappear beneath the Fickett series as a broad anticline, with the longer limb sloping gently southward and the shorter dipping more steeply northward, and probably playing an important part in forming the steep north front of the range, as has been shown to be the case to the east of the Anaktuvuk Valley.

In the foreground of Pl. IV, *B*, the Lisburne extends all the way across the field from left to right, but the sculptured cirque topography forming the top of the mountains in the left background lies in the slate and quartzite of the Fickett series, which, to the northwest, seems to overlie the Lisburne and form the crest of the range, and probably also descends the north slope and underlies the Mesozoics of the Anaktuvuk Plateau at the north base of the mountains.

The rocks of the Lisburne formation may be characterized for the most part as medium-bedded semicrystalline limestone of impure white or gray color. They weather gray, light rusty brown, or chocolate. They form the mountains that rise to a height of 2,500 to 3,000 feet above the floor of the Anaktuvuk Valley. Near the summit (see Pl. X, *B*, and fig. 4) occur two beds of intercalated shale, each apparently several hundred feet thick, and containing some thin layers of dark-gray limestone.

On the east the extent of the formation is unknown. On the south it is apparently in contact with the Carboniferous, while in descending the slope of the mountains on the north it disappears beneath a mantle of glacial till, where, judging from the topography, it is probably soon met and overlain by Mesozoic strata, which probably rest unconformably upon it at this point. (See fig. 4, p. 51.)

Judging from exposures observed in the region of the Anaktuvuk, the thickness of this limestone formation is probably a little over 3,000 feet.

Structure.—The entire area of the Lisburne formation here considered is deeply involved in the system of faulting and disturbed blocks referred to under the heading "Stuver series." As viewed from the Anaktuvuk Valley, looking either east or west (see section on Pl. III; also fig. 4 and Pl. X, *B*), the Lisburne series reveals but little of the disturbance it has undergone. On the southwest, however, toward Contact Creek, the rocks have been folded and broken into blocks, which in some instances are highly tilted. The fault on the west side of the Anaktuvuk, shown on the right of fig. 4, probably represents the westward extension of the same fault that gave rise to the scarp along the northern edge of the Stuver series, which series however, has not here been brought to view. At the north base of the mountains, west of the Anaktuvuk, the Lisburne formation disappears beneath the covering of glacial drift with a dip of 60° to the north. East of the Anaktuvuk it similarly disappears beneath the drift, but with an opposing dip at an angle of 75° S., against the fault scarp of the Stuver series, as shown in the section on Pl. III. Between these two localities the Stuver series probably attains a steep westerly dip, of which there is some suggestion along the north edge of the valley, or a portion of the valley may be traversed by a north-south fault extending from the north edge of the mountains to the southern limits of the Stuver series.

In certain localities, notably on the south side of the Anaktuvuk, the Lisburne is cut by a close jointing, trending N. 27° E., with dip southeast-east at an angle of 85° , dividing the rocks into thin slices from 2 to 8 inches in thickness.

There can be but little doubt that the faulting between the Lisburne and the Fickett series continues eastward and connects with that along the southern edge of the Bettles series, on Koyukuk and Chandlar rivers. Its alignment with the boundary of the Bettles series, as located in a previous year's work,^a is shown on the geologic map, Pl. III.

Age.—The most convenient disposition to make of the Lisburne formation would be to include it with the Fickett series and call the group Carboniferous and Devonian, since both Carboniferous and Devonian fossils occur freely in the stream gravels of the upper John and Anaktuvuk rivers, and none of the fossils found in place were sufficiently well preserved for identification. On lithologic grounds, however, the Lisburne formation can be set apart as quite distinct from the Fickett series, which it also seems to underlie. Therefore, on the basis of the Devonian fossils found in detached fragments of rock on the surface of the formation near the top of the mountains, and on the lithologic similarity of the rock attached to these fossils to that of the Lisburne formation, the formation is provisionally referred to the Devonian.

^aSchrader, F. C., Reconnaissance along the Chandlar and Koyukuk rivers, Alaska: Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 2, 1900, pl. 1x.

The fossils from the Lisburne formation collected by the writer have been identified by Mr. Charles Schuchert as follows:

Fossils of the Lisburne formation.

Locality 455.

Productella (2 species).

Platystoma.

Zaphrentis.

Fenestella.

Unitrypa.

Eridotrypa, nearly identical with *E. barrandei* (Nicholson) of the Middle Devonian.

Localities 460 and 462.

Spirifer disjunctus.

Localities 496, 498, 499, 501, 523, and 524.

Diphyphyllum (1 species).

Locality 500.

Zaphrentis.

Locality 528.

Aulocophyllum.

Locality 533.

Zaphrentis.

Rhombopora.

Fenestella.

Hemitrypa.

Localities 455 and 528 appear to be of one formation of the Middle Devonian. The species present suggest very much the Athabasca-Mackenzie Middle Devonian, collected many years ago by Kennicott and described by Meek in the Transactions of the Chicago Academy of Sciences.

Localities 460 and 462.

Spirifer disjunctus, one of the fossils characterizing the Upper Devonian. The same species is also found in the Peace, Hay, and Liard River regions of Arctic Canada.

Localities 496, 498, 499, 501, 523, and 524.

Diphyphyllum (1 species). This genus extends in America from the Upper Silurian to the close of the Middle Devonian, and will probably also be found in the Upper Devonian, so that, unsupported by other evidence, it does not indicate an exact horizon. This or a very similar species has been found at or near the mouth of Mackenzie River in Devonian rocks.

Localities 500 and 533 are probably also of Devonian age.

Correlation.—On lithologic grounds it appears that the Lisburne formation can safely be correlated with the medium-bedded, unsheared limestone portion of the Bettles series, which is best exposed near the mouth of Bettles River, on the Koyukuk,^a and it probably continues to the head of Chandler River. Thus this limestone formation extends from the region west of the Anaktuvuk eastward 100 or more miles, and the presence of Devonian still farther eastward, to the north of the Chandler, is rendered highly probable by a few fossils collected from the Chandler River gravels in 1899 by the writer.^b These fossils, a list of which follows, were identified by Dr. George H. Girty, whose statements thereon are here inserted.

^aSchrader, F. C., Reconnaissance along the Chandler and Koyukuk rivers, Alaska: Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 2, 1900, p. 475.

^bIbid.

Paleozoic fossils from the Chandlar River gravels.

- Locality 211. Indeterminable.
- Locality 22. *Syringopora* sp. 1.
- Locality 2. *Syringopora* sp. 2.
- Locality 47. *Spirifer*, *disjunctus* type.
- Locality 5. *Cyathophylloid* coral.
- Locality 203. Crinoid stems.

Syringopora, so far as known, is not found above the Carboniferous; therefore 22 and 2 can be referred, with little doubt, to the Paleozoic.

The spirifer of locality 47 represents a type which is not found below the Devonian, and is, in a measure, restricted to rocks of that age. This spirifer can pretty safely be referred to the Devonian, and if, as I suspect, the form is *Sp. disjunctus* itself or one of its close allies, probably to the Upper Devonian.

The coral found at locality 5 probably belongs to the genus *Acervularia*. The age indicated is certainly Paleozoic, and probably Devonian.

The crinoid fragments found at locality 203 indicate nothing positive as to age. From their character and abundance I should be inclined to determine the horizon as Paleozoic.

It should also be noted that the trend of the series continued still farther eastward, beyond the Chandlar River Basin, strikes the Porcupine near the Lower Ramparts, where Devonian forms were collected by Kennicott,^a and where Mr. McConnell, of the Canadian geological survey, reports the limestone to yield such fossils as *Atrypa reticularis*, with fragmentary specimens of corals referable, in part at least, to the Devonian.^b It seems highly probable that the Lisburne formation may also be correlated with the similar limestone and shale formation occurring at Cape Lisburne, which, though nearly 400 miles distant, undoubtedly represents the westward continuation of the same mountain axis. (See Pl. V and fig. 1, p. 40.) This suggestion is based, in a measure, on the statements of different persons who have found Paleozoic fossils in the Cape Lisburne region, and more especially on the recent reports of Mr. H. D. Dumars and Mr. A. G. Maddren. The fossils collected by Mr. Dumars in the region, with notes by the collector, have been presented by Mr. Maddren to the United States National Museum, where they have been examined by Mr. Schuchert, whose communication on them to the writer is as follows:

Paleozoic fossils from the Cape Lisburne region.

There is an interesting coral fauna of Middle Devonian age from "limestone cliffs 4 miles south of Cape Lisburne, just south of the mouth of a considerable stream, where the rocks strike east and west, and dip south at 45°" (Dumars). This limestone contains—

- Endophyllum*, 2 species.
- Syringopora*, near *S. tabulata*.
- Syringopora*, near *S. perelegans*.
- Diphyphyllum*, near *D. simcoense*.
- Diphyphyllum*, near *D. stramineum*.
- Zaphrentis*, probably 2 species.

This limestone appears to be the same formation as that discovered by you last summer [at head of Anaktuvuk River] at localities 496, 498, 499, 501, 523, and 524, but more particularly at 455 and 528.

^aTrans. Chicago Academy Sci., vol. 1, 1867.

^bAnn. Rept. Geol. Survey Canada, new series, vol. 4, 1890, p. 133 D.

In his field notes referring to this locality Mr. Maddren states that the limestones forming the cliffs referred to contain corals and other fossils and also veins of calcite. Fig. 1 (p. 40) is a profile section of the limestone and shale as sketched by Mr. Maddren at a locality a short distance south of the point where the fossils were found in place. The section includes Cape Lewis and Cape Dyer. So far as known, however, no fossils were found in the limestone represented in it. Cape Dyer is described as the sea terminus of a limestone range, about 1,000 feet in height, which trends inland in an easterly direction, the rocks striking east and west and dipping 35° N. In the valley between Cape Dyer and The Ears there is said to be a syncline of shale containing an exposure of coal along a sea cliff that rises from 50 to 100 feet above tide. The occurrence of coal here would seem to indicate the presence of some other horizon, probably Carboniferous or Mesozoic. According to Mr. Maddren the limestone beds at Cape Lewis also dip north and expose a thickness of 800 to 1,000 feet.

We may also note that the Middle Devonian discovered by Mr. Spurr in southwestern Alaska,^a in the Kuskokwim country, is considered by Mr. Schuchert as about the same as that on the Anaktuvuk. The same is true of the forms collected by Mr. Brooks in southeastern Alaska.^b

Distribution.—The thickness of the Lisburne formation in the mountains on the Anaktuvuk and at Cape Lisburne on the coast, and the important part it plays in the constitution of the Endicott Range and the continuation of these mountains westward to at least the one hundred and fifty-second meridian, as discovered by Howard,^c as well as the general regularity in the disposition of the rocks, seem to render it highly probable that that formation is continuous between the Anaktuvuk and Cape Lisburne. Its lithologic resemblance to the limestones of the Bettles series on the Koyukuk^d and the Devonian fossils found by the writer in the Chandlar River district, and by Kennicott and McConnell farther east on the Porcupine, would lead to the inference that the Lisburne formation, or at least the Devonian, forms a pretty constant component of this northern Rocky Mountain range from Cape Lisburne eastward throughout northern Alaska, for a distance of 600 or more miles, nearly to the international boundary and probably beyond it.

FICKETT SERIES (CARBONIFEROUS).

Character and occurrence.—The Fickett series, so named from the Fickett River of Allen (now called John River), comprises rocks of very diverse character, ranging from

^aSpurr, J. E., A reconnaissance in southwestern Alaska in 1898: Twentieth Ann. Rept. U. S. Geol. Survey, pt. 7, 1900, p. 179.

^bBrooks, A. H., Preliminary report on the Ketchikan mining district, Alaska: Prof. Paper U. S. Geol. Survey No. 1, 1902, p. 21.

^cStoney, Lieut. George M., Naval Explorations in Alaska, U. S. Naval Institute, Annapolis, Md., 1900, p. 70.

^dSchrader, F. C., Reconnaissance along the Chandlar and Koyukuk rivers, Alaska; Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 2, 1900, p. 475.

chloritic schists and phyllites on the south, through impure limestone, slate, sandstone, quartzite, and grit, to hard conglomerate on the north. As shown in the discussion of the Skajit, Totsen, Lisburne, and Stuver series, the Endicott Mountains contain two geologic axes, a northern and a southern, both composed of the older Paleozoic rocks, and, as represented on the geologic map and section (Pl. III), the Fickett series lies essentially in what appears to be a broad trough between these two axes. This trough or syncline, judging from the unconformity of the Fickett series to the Skajit and Lisburne formations, and the difference in character of the sediments, was probably occupied by an arm of the sea in late Paleozoic time, when the axes on the north and the south seem to have stood above sea level; and the sediments of the Fickett series, judging from their calcareous content, were probably in part derived from these Paleozoic land areas.

Here the Fickett series has a width, or north-south extent, of about 50 miles. On the south its edges appear to rest unconformably on the eroded Skajit formation of the southern axis, as shown in the geologic section, while owing to the faulting at the head of John and Anaktuvuk rivers its relations to the older rocks of the northern axis are not definitely revealed. It seems, however, to meet the Stuver series and the Lisburne formation by fault contact, as has been indicated. To the north of this contact, so far as observed in the region of the Anaktuvuk, all trace of the series in place seems to have been removed by erosion. To the west, however, beyond the limits of the fault-block system of the Devonian, about 20 miles from the Anaktuvuk, it seems to overlie the Lisburne formation, and probably extends beneath the Mesozoics at the north base of the range. From the occurrence of Carboniferous fossils in the stream gravels it is inferred that the same conditions probably prevail to the east of the Anaktuvuk, but they have not thus far been actually observed.

Beginning on the south slope of the north axis of the range, the lower part of the Fickett series, as it seems to be, consists of dark shale, schistose slate, and apparently some dark limestone, which is succeeded by quartzite, grit, and conglomerate. The sediments in the quartzite, and more especially those in the grit and conglomerate, though they are often fine, bear a marked resemblance to the vari-colored conglomerate of the Stuver series, from which they seem undoubtedly to have been derived. The quartzite, grit, and conglomerate are hard and flinty, the grains and pebbles being thoroughly united by a siliceous cement. The best exposure of these rocks that was seen is that at Fork Peak, on John River, east of camp July 12, from which point for about 15 miles northeastward, to beyond the Anaktuvuk portage, they present a steep face to the northwest, overlooking the upper part of John River Valley. Here the dip is gently south or southeast. Apparently these same conglomerates and grits were also encountered in the lower reaches of a deeply cut gulch about 20 miles south of Fork Peak, west of the mouth of Hunt Fork. Toward

the top of Fork Peak the grit and quartzite give way to dark schistose slate and dark-gray micaceous sandstone.

Southward, at a geologically higher horizon, gray sandstone, limestone, gray schist, some quartzitic schist, slate, and conglomerate are encountered. These rocks are medium layered, variously interbedded, and more or less sheared. In the region of Hunt Fork a dark-gray or bluish schistose sandstone and soft slate become predominant. Apparently ascending in the column, still farther southward, the rocks become for the most part very fine-grained gray or bluish quartz-schist, with finally greenish chloritic schist and slate, which continues to the southern edge of the series, where it rests unconformably on the Skagit limestone formation. The quartzitic schist and the green chloritic schist often carry considerable quartz in small veins and stringers, trending more or less parallel with the schistosity and the bedding. But exceptions occur, as shown in Pl. XI, A, where a species of gash veining breaks across the bedding. This quartz frequently is most abundant in the bights of sharp folds and along lines of strain and breaking. So far as observed, the veins carry no valuable metals.

Besides the above-noted rocks, light-gray and dark or black limestones, apparently belonging to the series, but not met in place along the route traversed, were sighted and studied with the field glass both southeast and southwest of Fork Peak. These limestones, judging from the resemblance to the specimens found in the stream gravels, are the mother rocks of the fossils occurring so abundantly in the streams. Their position in the geologic section seems to be above the conglomerate, grit, and quartzite portion of the section and near the dark schistose slate and dark-gray micaceous sandstone, as shown to some extent in Pl. VII.

Structure.—The Fickett series, like the other Paleozoics of the range, has been subjected to faulting and folding, incident to mountain building. The general structure, however, seems to be monoclinal, with strike and trend east and west and dip south at angles of 20° to 45° . The dip may vary, however, from southeast in some localities to southwest in others, while in certain cases the rocks lie nearly horizontal or dip very gently north. The prevailing southerly dip of the series as a whole seems to point to a greater and probably later elevation in the northern than in the southern part of the range since the Fickett was laid down.

The series is finely cut in some localities by the major nearly northeast-southwest jointing, whose planes are frequently slickensided and usually dip 70° to 80° NW. Slight movement, or normal faulting, has frequently taken place along them. The rocks are also traversed by a secondary set of joints, trending nearly northwest and southeast, with dip nearly vertical, or in some instances 60° to 80° SW.

The schists, and notably the slates, often exhibit excellent cleavages, a good

instance of which is shown at Crag Peak, 10 miles south of Hunt Fork and $4\frac{1}{2}$ miles west of John River. Here the cleavage trends N. 35° E. and dips northwest at an angle of 85° . Four miles north of this point, on the west side of John River, occurs another good instance, in which the cleavage trends N. 70° E., with dip to the north at an angle of 45° . Also where the river crosses the sixty-eighth parallel a cleavage is found trending east and west, with dip south at an angle of 30° .

Age.—No fossils have been found in place in this series, but on the basis of abundant Lower Carboniferous forms obtained in the stream pebbles of the region, and the lithologic resemblance of these pebbles to the rocks of the series, and also from the relation of the series to the Lisburne formation (which is considered Devonian and seems to underlie it), the Fickett series is provisionally assigned to the Lower Carboniferous. Following is a list of the fossil forms collected by the writer within the area occupied by the series, largely on the headwaters of John and Anaktuvuk rivers. They have been identified by Mr. Schuchert, who reports as follows:

Fossils from the Fickett series.

Locality 493. Lithostrotion (of the group in which the corallites are not in close embrace).

Locality 495. *Spirifer striatus* Martin, *Productus scabriculus* Martin, and *Spirifer* near *S. neglectus* Hall.

Locality 513. *Productus scabriculus* Martin.

Locality 520. *Productus semireticulatus* Martin.

Locality 521. *Spirifer striatus* Martin; *Productus*, a very small undetermined species, and *Cystodictya* nearest to *C. lineata*.

Locality 522. *Spirifer striatus* Martin and *Fenestella*.

Locality 525. *Spirifer striatus* Martin and *Spiriferina cristata* Schlotheim?

Locality 534. *Streblotrypa* near *nicklesi* Vine; *Fenestella*, several species, one of which is near *F. cestriensis* Ulrich; *Cystodictya*, *Pinnatopora*, and *Rhombopora*.

The above eight localities represent one formation, in the upper portion of the Lower Carboniferous. This fauna, however, is unlike that of the Mississippi Valley in that it does not have its characterizing fossils, as the screw-like bryozoan *Archimedes* and the blastoid genus *Pentremites*. Comparisons must be deferred until larger collections are at hand.

Localities 497 and 529 have a *Syringopora* much like *S. multattenuata* of the Upper Carboniferous. This genus, however, has little stratigraphic value, but the development of the species present is indicative of Carboniferous.

Localities 511, 518, and 454 are represented by a crinoidal limestone, apparently the same as at localities 525 and 521 and probably from the horizon of the latter.

Localities 463 and 464 represent another horizon, since the lithology is quite different from any of the other localities. The only fossils present are large crinoidal columns like those of the Lower Carboniferous.

Locality 461 also has large crinoid columns and may represent the Lower Carboniferous.

The above localities probably all represent the same Lower Carboniferous formation as that of the specimens from localities 493, 495, 513, 520, 521, 522, 525, and 534.

Locality 519 has *Fenestella*, *Cystodictya*? and crinoid columns. The material is unsatisfactory and all I can do is to state that it indicates either Devonian or Carboniferous.



A. QUARTZ GASH STRINGER VEINING IN FICKETT SERIES ON JOHN RIVER, IN ENDICOTT MOUNTAINS.
Looking southeast.



B. STRUCTURE IN ANAKTUVUK SERIES ON ANAKTUVUK RIVER.
Looking N. 10° W.



In referring the series to the Lower Carboniferous, however, it should be borne in mind that the fossils were nearly all found in the northern part of the field, where they have apparently come from near the lower part of the section, and since the series is possibly 8,000 to 10,000 feet in thickness, it may extend not only into Upper Carboniferous but possibly into Lower Mesozoic.

Correlation.—Carboniferous fossils have been collected by Spurr^a and Collier on the Yukon above Circle, by Mendenhall and the writer in the northern part of the Copper Basin, and by Dall in southeastern Alaska, on Kuiu Island, but these all seem to be Upper or Permo-Carboniferous, and therefore afford no ground for close correlation of the rock occurring there with those of the section here considered.

Independent of paleontologic evidence, on purely lithologic grounds, some of the gray schist, sandstone, and limestone beds of the series toward the northern part were associated by the writer in the field with the West Fork series of Chandlar River,^b which is regarded as possibly the source of some of the Paleozoic fossils found in the river gravels below that point, and which has been relegated by Doctor Girty to Carboniferous or Devonian.

Carboniferous forms are reported to have been collected on Captain Beechey's voyage,^c 1825–1828, on the northwest coast between Cape Beaufort and Cape Thompson (see Pl. V). More recently, in the Cape Lisburne region, plant remains have been collected by Mr. Dumars which have been identified by Mr. David White as a small species of *Lepidodendron*, related to *L. chemungense*, and a small form of *Stigmaria ficoides*, indicative of Carboniferous age. This denotes at least the presence of Carboniferous rocks in the Cape Lisburne region, which, on future investigation, may be correlated with the Fickett series, and suggests that the rocks of the two regions may be continuous in the mountains lying between them, as the Devonian is supposed to be. (See p. 66.)

In fact, if topographic criteria be taken into account—namely, the continuation of the mountains eastward beyond the international boundary—with what has been said of the occurrence of the Lisburne formation, it may here be briefly stated, in concluding the subject of Paleozoic rocks, that the present exploration, together with the evidence previously collected in the region to the east and that to the west, toward Cape Lisburne, seems to indicate beyond question the extension of a well-developed belt of Paleozoic rocks across northern Alaska, coinciding with the trend of the Rocky Mountains from the one hundred and thirty-fifth meridian, near the Mackenzie, to the one hundred and sixty-sixth, at Cape Lisburne, a distance of nearly 1,000 miles.

^aSpurr, J. E., Geology of the Yukon gold district, Alaska: Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 3, 1898.

^bSchrader, F. C., Reconnaissance along the Chandlar and Koyukuk rivers, Alaska: Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 2, 1900.

^cVoyage of Captain Beechey to the Pacific and Behring's Straits, London, 1836, pp. 378–405.

In the Cape Lisburne region, as noted, the belt has a known width of nearly 75 miles and the rocks terminate in abrupt sea cliffs. The thickness of the section here is not known, but from what has been learned of the attitude of the rocks, it is judged to be considerable, since nowhere do older rocks appear to be exposed beneath these Paleozoics; from which it seems safe to infer that the latter probably extend far seaward as a submarine feature; and as this part of the ocean is known in the main to be shallow, it seems not unlikely that the same formations may extend across its floor and appear on the Siberian coast. It may be noted, however, that Doctor Dall, who visited this coast, reports that the rocks on portions of it are essentially crystalline or igneous. Some lignite occurs on Wrangell Island, but we do not know that Paleozoic or other formations occur there.

MESOZOIC ROCKS.

CORWIN SERIES (JURA-CRETACEOUS).

Character and occurrence.—The name Corwin is proposed for a series of sedimentary rocks which are younger than the Fickett series and older than the Anaktuvuk series (next to be described). The name is taken from Corwin Bluff, in the Cape Lisburne region (see Pl. V), where the well-known coal mines of this name are located, and where rocks typical of the series are well exposed.

The rocks in the main have a strong lithologic resemblance to the Anaktuvuk series, and seem to be closely related to it in geographic and stratigraphic position, but as they are not known to occur in the interior along the route followed by this traverse, they will not be found represented on the geologic map nor in the geologic section. However, sufficient has been seen of the rocks along the coast from Wainwright Inlet to near Cape Lisburne to lead to the inference that they probably form a part of the trans-Alaskan Rocky Mountain system; and on topographic, geographic, and lithologic grounds, as shown in what follows, it has been concluded that they are intermediate between the Fickett and Anaktuvuk series, a view which is also supported by paleontologic evidence. The series contains the Wainwright, Cape Beaufort, Thetis, and Corwin coals, most of which are of good grade. The inland extension of the series is also further suggested by the occurrence of coal on the Colville, reported by Howard and by Reed (see p. 31).

As observed along the coast, the Corwin series seems to extend from near Wainwright Inlet, latitude $70^{\circ} 37'$, longitude $159^{\circ} 45'$, southwestward a distance of 180 miles or more, nearly to Cape Lisburne (see Pl. V). Beyond this point, farther inland, it seems to give way with marked unconformity to the Paleozoic rocks forming the core of the mountains terminating in the sea cliffs at Cape Lisburne and the coast south of that point (fig 1, p. 40).

The series was first examined by the writer in the low coastal bluffs near Wainwright Inlet, where the rocks consist of layers of dense, earthy-colored or dark-gray, soft, impure limestone or calcareous shale, and hard, bluish gray sandstone of medium grain, all interbedded with dull-bluish, softer shale. Here the land mass, composed in the main of these rocks, rises about 90 feet above sea level, and presents a nearly flat or very gently undulatory surface extending as far as can be seen.

Cape Beaufort (see Pl. V) marks the southern termination of this very gently undulatory or nearly flat lowland, which extends southwestward from Point Barrow, and which is underlain by rocks belonging, in part at least, to the Corwin series. As we near Cape Beaufort, in proceeding southward, the surface soon rises by a succession of low, minor ridges, of which the cape itself is the chief. This ridge is about 800 feet high, and is a portion of a warped and dissected plateau extending inland to the southwest (see Pl. X, C). The rocks of this plateau, though resembling the Corwin series, seem distinctly more indurated and bear the stamp of greater age. For this reason it is thought that they may, on further research, prove to be as old as Triassic or possibly Carboniferous, especially since Carboniferous fossils are reported to have been found somewhere in the region. For the present, however, the Cape Beaufort rocks are regarded as part of the Corwin series.

At Cape Beaufort the rocks consist essentially of thin-bedded, impure, gray and brown sandstone and arkose, with sometimes a little conglomeratic material containing lignitic plant remains. The sandstone is occasionally hardened, almost to quartzite. There is also some very impure limestone, and some coal.

Farther west, in the region of Cape Sabine (see Pl. V and Pl. X, C), considerable shale is also known to occur; and still farther west, in the region of the Corwin coal mines, the rocks, as exposed in the beach bluff, are mainly soft, impure, dull-greenish, gray, or brownish sandstone, shale, slate, and coal. Some more typical hard, gray sandstone, however, is also present. In general, the rocks occur in thin beds, from 1 to 2 feet in thickness, but occasionally there are layers 4 to 8 feet thick. These heavier members are usually sandstone.

Structure.—Excepting the tilt which the beds have received by uplift, giving them a general southerly dip varying from a very low angle to 40° or more, they have been but little disturbed. Some folding, however, and apparently slight faulting have taken place.

In the lowland near Wainwright Inlet the rocks are nearly horizontal or dip very gently southeastward. At Cape Beaufort the strike is N. 25° W., with dip southwestward at an angle of approximately 20° . In the region of the Corwin mines the strike is N. 45° W., and the dip 36° or more southwestward. Here the rocks are also cut by two systems of jointing, trending nearly at right angles. The one trends nearly northeast and dips northwest at an angle of 60° to 70° , while the

other trends nearly northwest, approximately parallel with the strike of the rocks, and dips northeastward at an angle of 60° to 70° . These jointings, however, do not cut up the rock greatly, not nearly so much as do those in the Lower Cretaceous rocks of the Anaktuvuk series in the interior.

Age.—Remains of fossil plants found in the Cape Beaufort region, and more particularly in the shale near the Thetis mine at Cape Sabine, by Mr. Dumars, Mr. Woolfe, and others, have been identified^a by Professor Fontaine and Doctor Ward as not older than the Oolitic of the Jurassic, nor younger than the Lower Cretaceous, and as probably transitional between the two. Similar evidence is afforded by fossil plants collected by the writer on the coast about 7 miles southwest of Wainwright Inlet, which have been identified by the same authorities as—

Nageiopsis longifolia Font.

Older Potomac of Virginia (Lower Cretaceous).

Podozamites distantinervis Font.

Older Potomac of Virginia (Lower Cretaceous).

Baiera gracilis (Bean) Bunbury.

Oolite of Yorkshire, England (Jurassic).

On the above evidence, therefore, the Corwin series is provisionally assigned to the Jura-Cretaceous.

Correlation.—Except the Kennicott^b formation in the Copper River district, no Jura-Cretaceous rocks with which the Corwin series can be correlated have thus far been found in Alaska.

ANAKTUVUK SERIES (LOWER CRETACEOUS).

Character and occurrence.—The Anaktuvuk series takes its name from the native name of the river along which it was observed by the writer. It underlies the southern or principal part of the very gently rolling Anaktuvuk Plateau, along the north side of the Endicott Range, whence, with surface sloping gently northward, it continues to form the country rock for a distance of about 50 miles, where it is succeeded by younger rocks.

Along the base of the mountains the series, judging from the topography (see Pl. IV), is believed to rest unconformably on the Devonian, or Lisburne formation. Of this, however, we have no conclusive evidence, as the actual relation between the two rocks was not seen, because of the covering of glacial drift. The first exposure of the series visited by the writer is about 8 miles from the mountains.

To the east the Anaktuvuk series is probably soon limited by the Paleozoic front of the range, while to the west and northwest it probably constitutes in part the

^a A full description of these collections, including the forms collected by the writer, will appear in Doctor Ward's second paper on the Older Mesozoic floras, to be published by the U. S. Geological Survey.

^b Schrader, F. C., and Spencer, A. C., *Geology and Mineral Resources of a Portion of the Copper River District, Alaska* (a special publication of the U. S. Geol. Survey), 1901, p. 48.

so-called Meade River Mountains, and, continuing northwestward, may extend to the Arctic coast.

The series consists essentially of impure sandstone or arkose, with a little fine conglomerate. The sandstone is usually heavy bedded, beds 6 to 8 feet in thickness being common, and it is generally fine to medium grained, but in some localities becomes so coarse as to be almost a grit. In color it ranges from dark or bluish gray to dirty greenish, while the coarser grained rock often presents a speckled or salt-and-pepper appearance, and is seen to be composed of grains of the variously colored flints represented in the Stuver conglomerate. In fact, the color of the rock throughout seems to be determined largely by the relative abundance of the different colored sediments from the Stuver series.

Northward from the mountains the rocks, though distinctly sedimentary, contain also some detritus of igneous rocks, as fragments of feldspar and some dark mineral, apparently augite or hornblende. The igneous rocks from which such sediments have been derived probably occur in the mountains lying far east or southeast of the plateau, as none were observed in the mountains in the region of the Anaktuvuk.

Conglomerate is apparently rare in the series, having been observed at but a single place—on the right bank of the Anaktuvuk about 2 miles below the mouth of Willow Creek, where it is exposed in a low point, interbedded with a few lens-like layers of sandstone. The conglomerate is typically rather fine, with scarcely a pebble exceeding three-fourths of an inch in diameter. The pebbles and cement are composed largely of sediments of the Stuver series, white quartz and dark or slate-colored flint being the most conspicuous. The pebbles are noticeable for their angularity, suggesting glaciation about the time the series was deposited. The cementation is relatively firm for a young rock, but is not comparable with that in the Stuver or Fickett series. The cement is mainly siliceous, but contains also calcareous material, probably derived from the Lisburne formation.

Owing to the low relief and the covering of drift and moss, no accurate idea can be formed of the thickness of the Anaktuvuk series, but it is estimated to be at least 2,000 feet.

Structure.—The strike of the Anaktuvuk series is approximately east and west, agreeing in this respect with the several series of rocks that compose the range to the south. Broadly considered the structure seems monoclinal. The rocks in general dip gently northward at varying angles, but subordinate gentle anticlinal and synclinal folds are present, the latter being occasionally open. These were probably caused by the same mountain-building forces that were exerted in the range to the south. This is suggested by the fact that the trend of the more pronounced folds in the plateau is parallel with the main folding of the range, as if all belonged to the same system. Besides the east-west major flexures, the plateau is also

traversed by a subordinate or minor system of cross folds or warpings, with axes trending north and south, giving rise to occasional low domes, as shown in fig. 3 (p. 46), which also shows that the region has been subjected to considerable denudation.

The series is freely traversed by two systems of jointing, as shown in Pl. XI, *B*. Of these, what seems to be the dominant or major system trends nearly northwest and dips southwest at an angle of 80° , while the minor system traverses the rocks at nearly right angles to the major, trending northeast, with dip 80° SE. Both systems seem to roughly correspond in trend with the similar structures in the Paleozoic rocks in the mountains to the south.

Age.—It has been determined, on paleontologic evidence, that the Anaktuvuk series is Lower Cretaceous. It contains typical *Aucella* beds of Alaska. The first fossils collected by the writer were found 8 miles north of the foot of the mountains. Subsequently others were found at several points farther north, principally at the first cross ridge on the Anaktuvuk, and in the bluff at the mouth of Willow Creek. Of these fossils the most characteristic, as determined by Doctor Stanton, are "*Aucella crassicollis* Keyserling, or closely related forms, and are of Lower Cretaceous age.

It should be borne in mind, however, that while its Jurassic forms prevent the Corwin series from being included with the Anaktuvuk series as Lower Cretaceous, it is not improbable that the discovery of such forms in the future may place the lower portion of the Anaktuvuk series, now assigned to the Lower Cretaceous, in the Jura-Cretaceous, since no fossils have yet been found in the extreme basal portion of the Anaktuvuk rocks.

Correlation.—On paleontologic grounds the Anaktuvuk series may be directly correlated with the Koyukuk series, next to be described. The rocks of the former, however, are free from all trace of igneous intrusions, while the Koyukuk series is associated with igneous rocks,^a as dikes, and probably also as flows.^b

Lithologically the Anaktuvuk rocks bear little or no resemblance to the Mission Creek series, assigned to the Cretaceous by Spurr,^c nor to the Kennicott formation or the Orca series of the Copper River district. As shown in the table of provisional correlation, several other series of rocks found elsewhere in Alaska have also been referred to the Cretaceous—the Matanuska series by Mendenhall, between Resurrection Bay and Tanana River; the Tordrillo, Holiknuk, Kolmakof, and Oklune by Spurr, in southwestern Alaska; and the Cantwell conglomerate by Eldridge,^d in the Sushitna River region.

^aSchrader, F. C., Reconnaissance along the Chandlar and Koyukuk rivers, Alaska: Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 2, 1900, p. 477.

^bP. 78, this paper.

^cSpurr, J. E., Geology of the Yukon gold district, Alaska: Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 3, 1898.

^dEldridge, G. H., A reconnaissance in the Sushitna Basin, Alaska: Twentieth Ann. Rept. U. S. Geol. Survey, pt. 7, 1898.

KOYUKUK SERIES (LOWER CRETACEOUS).

Character and occurrence.—The rocks of the Koyukuk series consist of pink and reddish impure limestone, dark shale, slates, and some sandstones or arkose, with occasional associated igneous rocks. The latter include dioritic dikes, amygdaloids, and andesitic tuffs, which denote volcanic activity during and subsequent to Lower Cretaceous time.

The series is represented as occupying a small, roughly quadrangular area near the southern edge of the geologic map, lying principally between the sixty-sixth parallel and the Arctic Circle on Koyukuk River. It, however, is known to extend southwestward considerably beyond the limits of the map, and may with further investigation be found to occupy a large part of the Koyukuk Basin. It is represented as limited on the northeast by the Bergman series, which in a general way it seems to underlie, and with which further study may show it to be closely connected in point of age.

Owing to wide breaks in the sequence of outcrops and the changing attitude of the rocks, no attempt will be made at present to form an estimate of the thickness of the series. It may be noted, however, that at one point where fossils were collected, near the southern edge of the map, on the right (or west) bank of Koyukuk River, the limestone exhibits a thickness of about 800 feet.

Structure.—The Koyukuk series has been variously disturbed by folding and by some faulting, but the prevailing dip, so far as observed, is northward, roughly speaking, at an angle of 40° to 45° . A profuse jointing trends N. 25° W., and dips steeply northeast, and a well-marked cleavage strikes northeast and dips 75° SE.

Age.—The age of the Koyukuk series is supposed by Doctor Stanton to be the same as that of the Anaktuvuk series. This determination is based on fossils collected by the writer in the impure limestone near the southern edge of the area mapped, on the right bank of the river, and at another locality a few miles farther down the stream, to the southwest. In each instance Doctor Stanton states that Lower Cretaceous age is indicated by the presence of *Aucella crassicollis* Keyserling.

Correlation.—See "Correlation" under Anaktuvuk series, page 76.

BERGMAN SERIES (CRETACEOUS?). ^a

Character and occurrence.—The term Bergman is here employed to designate a group of comparatively uniform rocks covering a large area in the Koyukuk Basin and forming in large part the Koyukuk Plateau (see p. 44). This series lies north of the Koyukuk series and has a north-south extent of 60 to 70 miles. On the north it rests unconformably on the schists of the Totsen series, while on the south it is apparently infolded with the Koyukuk series, to which it is supposed to be closely related and which it is supposed to succeed in geologic age.

^aThe name Bergman is that of a trading post on Koyukuk River situated within the area occupied by the series, at a point where its rocks have become exposed by the incision of the valley into the plateau.

The Bergman series consists essentially of thin- or medium-bedded, impure, gray or brownish sandstone and dark slate, with some dark shale and occasionally conglomerate, but along the north it is bordered by a belt of conglomerate about 10 miles wide which is apparently the basal member. The sediments of the series have been derived very largely from igneous rocks, as is shown by the generally feldspathic constituents of the sandstones and the presence of basaltic, diabasic, and granitic pebbles or finer detritus in the conglomerate on the lower part of Alatna River and at Lookout Mountain. The supposed basal belt of conglomerate along the northern border, however, so far as it was observed in the John River region, is composed essentially of the débris of limestone and mica-schist derived from the Skajit formation and the Totsen series, on which latter it unconformably lies. This conglomerate is normally coarse, and in some instances contains boulders.

Owing to the wide separation of the outcrops visited, data for forming an adequate estimate of the thickness of the Bergman series have not been obtained. From a general impression, however, it seems safe to suggest that it is probably at least 2,000 feet.

Structure.—The Bergman series, like the Koyukuk series to the south, has been considerably folded and somewhat faulted, but apparently to a less degree than the latter. Faulting has been observed on Koyukuk River just below Bergman and farther downstream, below Kanuti River. Though local folding has been pronounced, and the rocks are sometimes highly tilted and stand on edge, the prevailing dip of the series seems to be gently southward. On the whole the series does not seem to have received from the geologically late crustal movement the widespread tilt exhibited by both the Anaktuvuk series on the north of the range and the Koyukuk series on the south. Lookout Mountain apparently represents part of an anticlinal fold occurring in the series. Here the beds strike a little north of west and dip south at an angle of about 80° . A pronounced jointing trends northwest and dips 80° NE. A minor jointing trends north and dips east at an angle of 80° . On the north, where the beds apparently rest against the Totsen series, the dip is south at an angle of about 40° .

Age.—In 1899, owing to the presence of coal, lignite, and fragmentary plant remains in the beds, notably above Tramway Bar, and the resemblance of the beds in many instances to the Kenai formation occurring elsewhere in Alaska, it was conjectured that the rocks might be Tertiary and in part Kenai. The more extended observations made during the last season, though a large area of the series was traversed, have thrown no more definite light on the subject, for determining fossils were not found. It has been shown, however, that between Bergman and John River the series bears a marked resemblance lithologically to the Anaktuvuk series, or Lower Cretaceous, and that its rocks, on the whole, are more indurated than the

coal-bearing Upper Cretaceous or Nanushuk series, both occurring in the Arctic slope region. Judging from this, and from the seemingly close relationship of the Bergman series to the Lower Cretaceous or Koyukuk series, and the bituminous character of its coal content (No. 187 in table of analyses, p. 114), it seems probable that on further investigation the Bergman series is more likely to prove to be Cretaceous than Tertiary.

NANUSHUK SERIES (UPPER CRETACEOUS).

Character and occurrence.—This series is named from Nanushuk River, the native name of the stream on which it occurs, and which flows into the Anaktuvuk north of the middle of the belt. The series lies north of the Anaktuvuk series, which it seems to overlies unconformably, and is itself in turn overlain by the Tertiary Arctic coast strata, with which its relations are apparently also unconformable. The unconformity between the Anaktuvuk and the Nanushuk is inferred from the difference in the topography and the marked change in the character and attitude of their rocks. In the most northern observed exposure of the Anaktuvuk the dip is north, while in the most southern of the Nanushuk it is steeply south. The north-south width of the series, in the region of the Anaktuvuk, is about 30 miles, while its east-west extent is not known. It is probable that to the east it is soon delimited by the Anaktuvuk series, lying between it and the Paleozoics at the foot of the range. Westward, or rather northwestward, it may possibly extend to the Arctic coast, in the region between Point Barrow and Wainwright Inlet, but of this we have no paleontologic evidence.

Along Anaktuvuk River the topography of the Nanushuk series is of a character intermediate between that of the gently undulatory region of the Lower Cretaceous or Anaktuvuk series and that of the flat Tertiary coastal plain, whose terranes will be next described.

The rocks of the Nanushuk series are best exposed in the north bank of the Anaktuvuk about 5 miles above the mouth of Tuluga River. The exposure occurs in a bluff about three-eighths of a mile long that rises steeply 120 feet above the river (Pl. XII, A). The rocks, which here have a steep dip, are mainly thin bedded (Pl. XII, B). The beds range from 3 to 6 inches in thickness and exhibit rapid alternation. They consist of gray and brown sandstone, generally fine grained and sometimes friable, with some gray and impure fossiliferous limestone, dark shale, fine-grained gray quartzite, drab-colored and green chert, and black slate, stained reddish along the joints. Coal of good quality is also present (see analysis 107, p. 114). The beds strike N. 82° E., and dip south at an angle of 80°.

The above exposure seems to represent part of the south or upstream limb of an anticlinal fold which has been beveled off by erosion, for farther downstream the dip is north. Similar beds, probably belonging to the same series, were encountered,

but not examined, about 10 or 12 miles above this point on the opposite side of the valley. Northward toward the Colville, where they are finally succeeded by the younger formation of the Tertiary coastal plain, the beds seem to lie more nearly horizontal. They possibly floor the valley and form the bed of Colville River down to about 5 miles below the mouth of the Anaktuvuk. Here are rapids which probably mark the termination of the series in the river bed, though the rocks are no longer exposed in the banks. Below this point the bed of the Colville appears to lie in the younger and softer formations of the coastal plain, and the current continues slack nearly all the way to the coast.

Structure.—So far as observed, the strike of the Nanushuk series is about east and west, and though, from comparison with some of the older rock series, we might expect the prevailing dip to be northward, observation has hardly been sufficient to affirm that it is so. The apparent existence of at least one pronounced anticline has been shown in the previous paragraph. The series is traversed by a system of approximately horizontal jointing (Pl. XII, *B*).

Age.—On paleontologic evidence the Nanushuk series is assigned to the Upper Cretaceous. The fossils were nearly all collected in the locality above described—on the north bank of the Anaktuvuk 5 miles above the mouth of the Tuluga. They have been identified by Dr. T. W. Stanton, who reports the lot to be certainly of Upper Cretaceous age. The forms identified are as follows:

Fossils of the Nanushuk series from bank of Anaktuvuk River 5 miles above mouth of Tuluga River.

Inoceramus, a rather large species, fragmentary specimens.

A small Astarte, numerous specimens.

Nucula, numerous specimens.

Avicula.

Pectunculus, several specimens.

Thracia.

Tellina, 2 species.

Siliqua.

Modiola.

Scaphites.

Haminea.

Besides the above, there are casts and impressions of numerous bivalves not yet determined.

Concerning the above list, Doctor Stanton remarks that the species are all apparently different from those with which he is familiar, but that several of them are of types known only in the Upper Cretaceous.

Correlation.—Upper Cretaceous rocks occur also to the south of the Endicott Mountains in the Koyukuk and Yukon Basin, between the southern edge of the



A. BASE-LEVEL FEATURE IN NANUSHUK SERIES ON ANAKTUVUK RIVER.
Looking N. 30° E.



B. STRUCTURE AND RAPID ALTERNATION IN BEDDING IN NANUSHUK SERIES ON ANAKTUVUK RIVER.
Looking N. 70° E.



area here discussed and Nulato, and include, in part at least, the so-called Nulato sandstone. A description of this series was given in a previous report.^a The fossils on which the assignment is made were collected by the writer in 1899 in the Nulato sandstone between Pickart's coal mine and Nulato, and are of interest as being the first Upper Cretaceous fossils found in Alaska. Of this collection, Doctor Stanton has reported the following forms, and refers the beds to about the same horizon as the early Chico of the Pacific region in the United States:

Upper Cretaceous fossils from the Yukon Basin.

Ostrea.
Anomia.
Mytilus.
Cardium.
Opis?
Lucina.
Trigonia cf. *T. leana* Gabb.
Corbula.
Actæonella cf. *A. oviformis* Gabb.

East of the international boundary both Upper and Lower Cretaceous fossils have been found on the Porcupine by Mr. R. G. McConnell, of the Canadian geological survey.^b

TERTIARY ROCKS.

COLVILLE SERIES (OLIGOCENE AND PLIOCENE).

Character and occurrence.—The Colville series is named from the large river along which it occurs and is excellently exposed. It is a series of Tertiary terranes which underlies the flat tundra country, or Arctic Coastal Plain, that succeeds the more southerly rolling plain formed by the Upper Cretaceous or Nanushuk series, which it apparently unconformably overlies, being itself in turn unconformably overlain by the Gubik sands. The strata which have been thus grouped extend along the Colville from some distance above the mouth of the Anaktuvuk nearly to the Arctic coast, occupying a belt 80 to 100 miles wide. Judging from the topography, the series probably has a very considerable extent in an east-west direction, possibly reaching the northwestern coast in the region of Point Barrow and farther southward. It also appears along the northern coast in places between Point Barrow and the mouth of the Colville, but has not been recognized.

The inland edge of the coastal plain, formed essentially by this series, has an elevation of about 800 feet, from which, with very gradual slope, the surface descends approximately to sea level at the coast. Beyond this, the very gradually deepening

^aSchrader, F. C., Reconnaissance along the Chandlar and Koyukuk rivers, Alaska: Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 2, 1900.

^bAnn. Rept. Geol. and Nat. History Survey of Canada, vol. 4, 1888-1889, Montreal, 1890, pp. 122-125 D.

sea floor seems to be its continuation. Thus the subaerial tundra country and the submarine coastal shelf almost appear to be parts of the same plain. Beneath the sea, deposition is still active, while on most of the surface of the subaerial portion of the plain the work of erosion has hardly yet begun.

The series consists principally of heavy-bedded silts, soft sandstone, limestone, shale, and lignite. It is best exposed along the Colville in the region of the mouth of the Anaktuvuk, where it forms steep-faced bluffs about 200 feet in height, extending for a number of miles both up and down the river (Pl. VIII).

Structure.—The Colville series has been but little disturbed. The beds lie nearly horizontal. On the left bank of the Anaktuvuk, 10 or 12 miles above its mouth, they dip southward at an angle of 4° or 5° , but from near the mouth of the Anaktuvuk, along down the Colville nearly to the coast, they dip northward or northeastward (see Pl. VIII), so gently that great care is required to detect the introduction of successively newer and younger beds, as one ascends the geologic section in proceeding northward downstream. In the vicinity of the mouth of the Anaktuvuk some very broad, shallow depressions or folds are revealed. Above the mouth the dip is northward, at an angle of 8° to 10° , but a few miles below it is southward at about the same angle, so that the lower part of Anaktuvuk River seems to lie in a very shallow syncline.

Besides this gentle folding, the beds have also suffered slight faulting (see Pl. VIII, *B*). The maximum vertical throw in the faults observed is about 2 feet. Lateral crowding has also taken place, producing local crumpling or folds and small overthrusts, as shown in Pl. VIII, *B*, *C*, and Pl. XIII, *A*. In nearly all cases the crowding or thrust seems to have come from the south, indicating that crustal movements have apparently taken place in the mountain region in geologically recent time. The inland or upstream side of any particular stratum which has been broken or disturbed has been crowded or overthrust onto the coastal or downstream side of the same, often producing a short overlap. Disturbance, however, is hardly noticeable in the younger Pliocene portion of the beds toward the coast.

Observations made along Colville River indicate that the series has a thickness of 500 or 600 feet.

On account of difference in degree of consolidation of the beds, together with their fossil and lignite contents, the series has been separated by the writer into two parts, upper Colville and lower Colville. It is possible that an unconformity may exist between the lower and upper parts of the series, but if present it must be very slight.

Lower Colville (Oligocene).—This constitutes the main portion or lower three-fourths of the section exposed at the mouth of the Anaktuvuk. It is about 150 feet thick, while the upper Colville at this same locality is about 40 to 50 feet thick.



A



B.

STRUCTURE IN COVILLE SERIES (TERTIARY).

A, Looking S. 50° W.; *B*, looking S. 65° W.



C COAL BED AND ROCKS OF CORWIN SERIES AT CORWIN MINES.

Looking S. 45° E.



The lower Colville contains the more indurated class of rocks and consists mainly of partially consolidated silts in beds 6 to 8 feet in thickness. They are usually light slate-colored or ash-colored, and constitute about one-half of the lower Colville section, and are generally much less consolidated toward the top than near the base. The harder rocks, which increase in volume toward the base of the section, include impure, dull gray, medium to fine grained sandstone with detrital lignitic plant remains; slate-colored and brownish calcareous shale, with disseminated undeterminable vegetable detritus; lignitic coal in layers 1 to 5 feet in thickness; dark slate-colored or brownish chert, containing cavities incrustated with chalcedonic silica; rusty brown, very ferruginous sandstone or impure iron stone, and some iron-stained siliceous conglomerate, which also contains lignitic vegetable remains. There are also a few layers of hardened silts, forming a rock of very fine texture, resembling soft, smooth hone stone.

The lower Colville is tentatively classed as Oligocene, on account of the presence in it of lignite beds and vegetable remains, and from its resemblance to the Kenai beds occurring elsewhere in Alaska, and also on the ground of its relation to the supposed Pliocene silts which it immediately underlies. Several specimens of the shale collected from it, bearing lignitic plant remains, were examined by Doctor Dall, who reports that "the vegetable fragments are probably the needles of *Sequoia langsdorffii* Heer. These beds containing vegetable remains in northern Alaska are usually Upper Oligocene."

Upper Colville (Pliocene).—This portion of the section is practically free from indurated rock. It consists of nearly horizontally stratified beds of fine gray, slate-colored, or ash-colored calcareous silts, containing faunal remains. It is tentatively assigned to the Pliocene on the basis of fossils collected in place by the writer in the bluff (near its top) on the west side of the Colville about a mile north of the seventieth parallel (Pl. XIV, A). These have been reported on by Doctor Dall as follows:

Fossils from upper Colville series in bluff on west side of Colville River 1 mile north of seventieth parallel.

Chrysodomus, 2 species, both undescribed and very interesting; the first Tertiary arctic shells (not Quaternary) I have ever seen. Perhaps they are Pliocene.

Amauropsis sp., fragments.

Tachyrhynchus polaris Beck.

Macoma frigida Hanley.

Macoma incongrua von Martens.

Astarte semisulcata Leach (possibly Quaternary intrusion).

Saxicava arctica L.

PLEISTOCENE DEPOSITS.

GLACIAL DEPOSITS AND GLACIATION.

Glaciation in geologically recent time in northern Alaska has not been of a continental character comparable to that of the northern United States and of the Cordilleran glacier, which overspread the vast field of the Pacific coast mountains in southern Alaska between the Yukon and the coast. It has been far more extensive, however, than has generally been supposed. In the valleys nearly everywhere within the Endicott Range evidence of ice action is shown by bed-rock scorings, local roches moutonnées, terminal moraines, and deposits of till on the lower valley slopes and benches. It has modified preexisting topographic forms, both by erosion of the rocks and by deposition of drift. In some cases, as revealed in places by erosion of the glacial deposits, steep-faced bed-rock benches in the sides of the valleys were covered and concealed by the drift, whose surface slopes gently down from the steep mountain side a distance of one-half mile or more, nearly to the present stream (Pl. XIV, *B*).

In the lower part of the intramontane section of John River, where the valley occasionally widens, it is sometimes floored by a till sheet, from 50 to 100 feet thick, containing ponds and lakelets, some of which seem distinctly to be of glacial origin. Till is prominent also in the mouths of some of the side valleys, as Till Creek Valley, which opens into that of John River on the east at about the sixty-eighth parallel. Here good exposures show the deposit to be typical till. It has a thickness of at least 100 feet, and forms a broad terrace or sort of small, triangular plateau a mile or more in extent, occupying the mouth of the side valley. It slopes westward, to where John River has been crowded to the bluffs on that side of the valley. On the east it overspreads and conceals the lower benching and bed-rock topography. Till Creek, a torrential stream, flows in a small canyon whose steep banks are formed of the boulder clay or ground moraine.

In the region of Fork Peak, near the head of John River, at the confluence of several of its tributaries, the valley is wide and open and is floored by a till sheet at least 150 feet in thickness. The surface declines to the southwest, denoting that the deposit has largely come from the northeast, a view which is supported by bed-rock striæ farther down the valley. The till ascends the northwest slope of Fork Peak to an elevation of 2,500 feet, and may continue much higher, but becomes obscured by younger talus and coarse débris of doubtful character, which, however, also exhibits an ill-defined terminal moraine topography. At the elevation of about 3,500 feet is a bench overlain by talus and drift, which, judging from topography, was probably largely deposited by a local hanging glacier.



A. PLIOCENE FOSSIL LOCALITY IN COLVILLE RIVER BLUFFS (COLVILLE SERIES), TERTIARY COASTAL PLAIN.
Latitude $70^{\circ} 1'$; looking N. 25° W. Native Eskimo family in foreground.



B. GLACIATION IN UPPER JOHN RIVER VALLEY, IN ENDICOTT MOUNTAINS.
Looking S. 25° W.

The John Valley till sheet extends across the divide by way of Anaktuvuk Pass and is continuous with that of the Anaktuvuk Valley and the Arctic slope. At the pass the valley is 3 miles wide and open, and its surface is so flattened with infilled drift that the small streams descending from the mountains in this locality are deflected by the merest obstacle to either side of the divide, flowing sometimes northward by way of the Anaktuvuk to the Arctic, and at others southward to John River and the Yukon.

At the pass occur lakelets of glacial origin. One of these, Cache Lake (Pl. X, *B*), just northeast of the divide, is 30 feet or more deep. Its surface lies about 100 feet below that of the adjacent ground moraine, giving for the till sheet here a thickness of at least 130 feet. Just south of the pass the till sheet formerly extended entirely across the valley, as is shown by the flat-topped outlying remnants of ground moraine in its middle. These rise to the height of more than 100 feet above the stream, and accord in level with the ground-moraine terraces on either side.

On the whole, the till sheet in this northern part of the range seems rarely to extend up the side slopes to more than 500 or 600 feet above the floor of the valley. Judging, however, from the rounded and sometimes relatively flat-topped aspect of the mountains near the middle of the range (Pls. XIV, *B*, and XV, *A*), certain areas were not only occupied by an ice cap, but the tops of some of the lower mountains were planed off by ice movement.

Naturally, the side-valleys in this region were among the last to become free from glaciers, some of which probably remained long after the disappearance of the ice from the adjacent parts of main valleys. This is shown by the presence of relatively fresh terminal moraines in the side valleys. Four miles northwest of the middle of John River Valley the small valley of Contact Creek is crossed by such a moraine. It is typical, being about 60 feet high and one-fourth of a mile in length, measured parallel with the valley. A similar but older feature occurs in John River Valley, near the middle of the range, about 12 miles in direct line south of the sixty-eighth parallel. Here the valley flat is crossed by a terminal moraine about 60 feet high, a portion of which is shown in Pl. XV, *B*. It still forms a continuous ridge or dam across the valley, except where the river has cut a notch-like passage, 200 yards wide, at the left. At the right the moraine seems to be continuous with the till sheet, which is 10 to 20 feet thick, and rests on the bed-rock benching at a height of about 100 feet above the river. As seen in looking parallel with the valley, the ridge presents an undulating profile and is sharp-crested, owing to its upstream side being cut away by the river. Though it exhibits but little of the typical hummock-and-kettle topography of a terminal moraine, it is composed mainly of typical boulder clay carrying striated pebbles and boulders, some a foot or more in diameter. The materials noted are of the same constitution as those of the river gravels, there being

no erratics. The principal surface or front of the moraine, which slopes southward, supports a growth of spruce, some of the trees having a basal thickness of $1\frac{1}{4}$ feet.

A few miles above this moraine occurs the last lingering remnant of the John Valley Glacier. It consists of a lone, roughly circular mass of ice about 300 feet in diameter, rising from the middle of the gravel-covered valley flats to a height of 60 feet, as shown in Pl. XV, A. At the top the ice terminates in several distinct knob-like prominences, projecting 10 to 20 feet above the main mass. One of these is cylindrical or pipe shaped. The others are crudely pyramidal. The ice is partially capped and flanked by a deposit of genuine till from one to several feet thick, to whose protection it doubtless in large measure owes its preservation. From three sides small streamlets of light-colored muddy water, arising from the melting of the ice and thickened with glacial rock flour from the till, flow down and deposit their load of fine, argillaceous sediment over the flats around the foot of the mass. This glacial mud is of very light color. It is sticky, and differs decidedly from the present stream deposits of the valley. This ice mass is undoubtedly a remnant of the John Valley Glacier. Its presence at this late date, after apparently all the other glacial ice has disappeared from the surrounding region, together with the rounded topography of the adjacent mountains, already noted (Pl. XV, A), suggests that this locality is probably near what was the belt of maximum precipitation, and consequently of maximum ice accumulation, that traversed the mountains during Glacial time, and is therefore among the last to become free from ice.

In the north slope of Anaktuvuk Pass, between John and Anaktuvuk rivers, the till topography is locally rough and in part terminal morainic. North of Cache Lake it contains occasional stretches of distinctly termino-lateral moraine, trending toward Anaktuvuk River, and for the last 10 or 12 miles of its course, before leaving the mountains, the Anaktuvuk meanders sluggishly through a belt of flats one-half mile or more in width, which lie about 100 feet below the surface of the till sheet or ground moraine on either side. This till sheet, with a slope that rises gently in the main, but which is sometimes terraced, extends from the edge of the flats to the base of the mountains, $1\frac{1}{4}$ miles distant. Near the flats the topography is often of a morainic type, being composed of characteristic hummocks and kettles, and undoubtedly represents a lateral moraine, deposited along the edges of the valley glacier that occupied the flats toward the close of Glacial time.

The height to which the drift, as a sheet, rises along the northern edge of the mountains away from the Anaktuvuk Valley was not determined. Judging from distant observations, however, it in some cases probably ascends the valleys to 800 to 1,000 feet above the general level of the Anaktuvuk Plateau.

As Anaktuvuk River leaves the mountains its current becomes less sluggish and its channel is soon beset with glacial boulders. At about $4\frac{1}{4}$ miles from the edge



A. ICE REMNANT OF JOHN VALLEY GLACIER IN ENDICOTT MOUNTAINS.

Looking southwest.



B. TIMBERED TERMINAL MORaine RESTING ON FICKETT SERIES ON JOHN RIVER.

Looking southwest.

of the mountains the river bluff on the left exposes a thickness of a little over 100 feet of typical till. From this point the deposit continues laterally up the side slopes of the valley, and apparently overspreads the plateau indefinitely, while the lower portions of the deposit, extending downstream, form terraces along the river. At about 10 miles from the mountains and $2\frac{1}{2}$ miles east of the river, at an elevation of 2,400 feet, or nearly 700 feet above the valley floor, the top of a rounded sandstone hill, which rises to the general level of the plateau, bears patches of till a foot or more in thickness. Here, too, some of the less firm portions of the bed rock have been disturbed, while others bear markings that have been interpreted as imperfect glacial striæ. These trend approximately parallel with the valley. A view of the surface of the plateau from this point, as shown in Pl. IV, seems to indicate the presence of drift almost everywhere, though the deposit is probably thin on the tops of the higher ridges.

Till occurs farther down the Anaktuvuk, forming terraces and moraines similar to those noted in the intramontane section of the valley. About 15 miles north of the mountains, just below camp July 1, on the side of the valley, there is a lateral moraine that rises to a height of about 150 feet above the valley flat, which is here about three-fourths mile wide. The steep angle, 45° to 60° , at which the drift materials lie, as exhibited in the face presented to the valley, clearly denotes that they were deposited largely against an ice wall. Just in front of this moraine is a characteristic overwash plain from whose upper edge an unquestionable terminal moraine extends indefinitely, both to the east and to the west, away from the valley.

A little north of the above region, about 23 miles from the mountains, occurs the first pronounced cross ridge of Lower Cretaceous beds, through which the river has cut a short canyon. A few miles east of the river this ridge attains an elevation of about 2,500 to 2,600 feet. On ascending the ridge in this vicinity, from the plateau on the south, the till sheet was found to continue up to the elevation of about 2,250 feet, where, on the slope becoming a little steep, it suddenly ceases and the bed rock becomes exposed and continues so across the broad top of the ridge, while till is again encountered on its north slope, which descends into Willow Creek Valley.

On the top of the above ridge, however, are glacial erratic boulders, which, though not abundant, are decisive in showing that an ice sheet passed over the ridge. As these erratics occur 400 to 500 feet above the ground moraine, it is inferred that they were probably transported as englacial or superglacial material. Here, also, large blocks of bed-rock sandstone have been moved from their original position to an extent that can not be accounted for by frost or weathering, so that their transportation seems to have been the work of moving ice.

About 10 miles northward, on Willow Creek Ridge, a similar feature, no glacial drift was found. At a few points the edges of the sandstone beds are disturbed, as

if by ice action, but the evidence as to the agency is not conclusive. On descending the slope northwestward, however, toward the Anaktuvuk, erratics of the Stuver conglomerate were found at an elevation of about 1,650 feet. The surface in this locality, however, is so densely covered with moss that drift may extend above this elevation and yet not be exposed. But on the whole, from this point northward, the till seems rapidly to become restricted to the lower side slopes of the valley, where it forms low bluffs and terraces.

About 14 miles below Willow Creek, near camp August 5, bluffs of probable till, resting against the bed-rock sides of the valley, rise to a height of 125 feet above the valley flats, and there, apparently as a thin veneer, the deposit over-spreads the adjacent bed-rock bench. This bench is half a mile or more in width, nearly flat topped, and densely covered with vegetation, so that away from its river edge no satisfactory examination of the deposit could be made. A few hundred feet above the upper or distal edge of the bench, however, are outcrops of sandstone, presenting no drift or indication of ice action.

Twelve miles north of the above locality, about five miles above the mouth of Tuluga River (see Pl. XII, A), a similar bench, lying at 100 feet above the river, is capped by a deposit of gravel and sand 20 feet in thickness. Some of the pebbles approach the size of boulderets, and even boulders. Though they are waterworn, no stratification is apparent in the deposit, which has much the aspect of a sandy till. Its position suggests that it may have been deposited here by waters from the glacier that possibly occupied the valley at this point. The deposit may, however, be fluvial.

Sixteen miles farther down the Anaktuvuk, about 10 miles above its mouth, the bluff on the left is again capped by from 10 to 40 feet of sand and gravel, in which the gravel is more distinctly washed and rounded than in the deposit above noted, but the absence of stratification and the character of the material again suggest that glacial waters may possibly have been an agency in its deposition. If this inference is correct, the ice stream which occupied the Anaktuvuk valley must have extended down nearly to this point. There is, however, no reason to suppose that it extended below it. On the adjacent part of Colville River there seems to be no evidence of glaciation within a score or more miles above the mouth of the Anaktuvuk. The drainage of this section of the Colville does not seem to have been interrupted since the Tertiary.

From the conditions above described it is concluded that in the region of the Anaktuvuk Valley, in that portion of the Colville Basin embraced by the curving front of the Endicott Mountains, an ice sheet in the form of a small regional or piedmont glacier, gradually thinning out toward the north, extended from the front of the range northward across the inner part of the Anaktuvuk Plateau to the region of Willow Creek, a distance of 30 or more miles. Beyond this point ice flowage seems

to have been confined substantially to the present drainage ways, in the form of valley glaciers, of which that of the Anaktuvuk is the chief.

There is evidence that the Anaktuvuk glacier extended northward to the sixty-ninth parallel, and there are some indications that it may possibly have extended 30 miles farther, to within 10 or 12 miles of the present mouth of Anaktuvuk River, but it is not to be supposed that it crossed Colville River, if indeed it ever reached it. This latter statement is probably also true of the ice streams to the west that must have occupied the valleys of Ninuluk, Killik, Kurupa, and Kucher creeks, which enter the Colville a little north of the sixty-ninth parallel.

It does not seem probable that the drift sheet on the Arctic slope much exceeds 150 feet in thickness at any point. It apparently attains its maximum development in the valleys, not far from the mountains, the source of supply. Elsewhere on the slopes its surface seems to conform very largely to the preexisting topography of the underlying terranes.

In the southern part of the Endicott Mountains, evidence of glaciation, as has been shown, may be found up to an elevation of nearly 2,000 feet. From the point where John River leaves the mountains, southward to the region of Kanuti River, the Koyukuk Valley region exhibits a generally rounded topography, which suggests former glaciation, up to a height of 1,600 or 1,800 feet. On John River, near the base of the mountains, the drift, so far as observed, is essentially till. In some localities the deposit is at least 100 feet thick, and is marked by several terraces that rise successively from the river to the southeast, above which the surface continues to have a rolling, apparently ground-moraine topography, that finally gives way to low, rounded mountains or hills, which also are supposed to be glaciated.

Observations in the above region away from the immediate route of travel were very limited. Along the route, however, glacial drift seems to be more or less continuous all the way down the open flats of John River Valley, as is shown by the topography and by occasional exposures of till rising to a height of 30 or 40 feet above the river or resting in thinner sheets on the bed-rock benches at elevations of from 30 to 100 feet above the stream.

Till is present near the mouth of John River and on the right or west bank of the Koyukuk between Bettles and the mouth of Jane Creek, where it forms bluffs about 100 feet high. Similar conditions seem to prevail to the eastward, in the region of Gold Bench^a on South Fork, whence they apparently continue northeastward across the divide into the Chandlar River Basin, where till deposits similar to those on John River have been noted in a previous report, and have since been observed to extend up Granite Creek.^b

^a When the only opportunity for making observations at Gold Bench was presented, 5 feet of snow lay on the ground.

^b Reconnaissance along the Chandlar and Koyukuk rivers, Alaska: Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 2, 1900, p. 478.

No glacial drift was noted on the top of Lookout Mountain, and, as the surface was deeply snow covered at the time it was visited, the elevation to which the drift ascends on its slope could not be learned. Southward, on the northeast side of the lower Alatna Valley, what seem to be till terraces occur along the south side of Double Mountain up to a height of 1,600 feet.

Just below the mouth of the Alatna the right bank of the Koyukuk presents a steep-faced exposure of clay and gravel, rising 80 to 100 feet above the river.^a The lower 50 feet of this section seems to be till, and is distinctly separated by a well-defined contact from the upper portion, which consists mostly of gravels and silts, some of which are discordantly stratified.

From the character of the topography glacial drift is supposed also to occur on the opposite side of the Koyukuk and to extend southward toward the mouth of Kanuti River. Mr. Mendenhall reports that in the country lying north of this region, on the upper waters of the Alatna and the Kowak, above the sixty-seventh parallel there is evidence of glaciation similar to that in the same latitude on John River. Furthermore, in the recent gravels along the Koyukuk near Bergman, notably on the south side of the river, there are large granitoid boulders, totally foreign to the country rock of the region. These may have been brought here through the agency of river ice from far up the valley of South Fork, but it seems equally probable that they may have been brought by glaciers from the mountains to the north where similar rocks in place are known to occur.

The hill just west of Bergman consists of Bergman sandstone, but on its slope, at a height of nearly 200 feet above the river, there is a gravel deposit composed of heterogeneous materials. An examination, as thorough as could be made under unfavorable conditions, indicates that ice action was concerned in its origin. It contains characteristically angular and subangular ice-worn pebbles, with polished surfaces, often profusely striated. The striæ are of distinctly glacial origin and can in no wise be ascribed to the action of river ice.

From the above-enumerated observations in this southern part of the field it is inferred that glaciation extended from the mountains southward into the Koyukuk Basin across the Arctic Circle and beyond Bergman, but observation has not been sufficient to determine whether this extension was in the form of a continuous ice sheet, or merely as valley glaciers. From topographic criteria, however, it seems probable that most of the hills below 2,000 feet were covered by ice or *névé*, while such peaks as Mount Lookout and its higher fellows appeared as nunataks above its surface, and that glacial activity, or ice work, was largely restricted to the valleys and lower reaches of the hill slopes.

In the John River and Anaktuvuk River portions of the Endicott Mountains the

^aThis bluff is the Unatlotly of the natives.

glacier ice (save the single instance cited on John River) has disappeared. To the east, however, as noted under "Previous explorations," prospectors and whalers who have crossed the range in the vicinity of the one hundred and forty-ninth meridian report the presence of valley glaciers of considerable size.

The glacial phenomena that have been described tend to show that, although the Endicott Mountains (Pl. VII) do not on the whole seem to have been overridden en masse by a moving ice sheet, they were doubtless, especially in their northern part, largely occupied by an ice cap or perennial névé, constituting a breeding ground for glaciers. The zone of maximum snowfall, and consequently of maximum ice accumulation, trending in an east-west direction, was apparently in the northern part of the range at least somewhat north of its median line. From this zone the ice moved off to the north and to the south, respectively, into the Colville and Koyukuk basins. Its flowage, especially during the latter part of the Ice age, was confined mainly to the valleys and drainageways in the form of alpine glaciers, of which there is ample evidence. But there is also good reason to believe, as shown by the till sheet north of the mountains, that during the zenith of the Ice age the northern edge of the range was occupied by a more or less extensive ice sheet, which, as a small regional or piedmont glacier, thinning out toward the north, extended northward over a considerable portion of the Anaktuvuk Plateau, its occurrence at that time being, perhaps, similar to that of the Bering or Malaspina glaciers of to-day.

GROUND-ICE FORMATION AND KOWAK CLAY.

At some localities along the Arctic coast there are stretches of low bluffs or banks of ground ice overlain by a deposit of dark muck and moss several feet in thickness. Deposits of light-colored clay also are occasionally seen. The occurrence and distribution of these deposits appear, in a measure, to be as represented by Doctor Dall on his map of the "Known distribution of the Neocene formations in Alaska."^a

The ground-ice formation was hitherto supposed to be of very widespread occurrence in this Arctic region. To give an idea of the evidence on which this supposition rests I shall here freely quote from Doctor Dall's report.^b

"From information gathered from several masters of vessels in the whaling fleet, and derived from experience gained in the effort to dig graves for seamen who had died aboard vessels on this shore from time to time during the last twenty years, it would appear that somewhat north of Cape Beaufort the land between the low hills and the sea is low and the soil chiefly a sort of gravel. 'At a depth of 2 feet is a stratum of pure ice (not frozen soil) of unknown depth. This formation extends, with occasional gaps, north to Point Barrow, and thence east to Return Reef, where

^a Dall, W. H., Correlation papers, Neocene: Bull. U. S. Geol. Survey No. 84, 1892, opposite p. 268. Becker, G. F., Reconnaissance of the gold fields of southern Alaska: Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 3, 1898, pl. 1.

^b Op. cit., p. 264.

the ice layer is about 6 feet above the level of the sea. It goes south at least as far as Icy Cape without any decided break, and is found in different localities as far south as Kotzebue Sound.' At Point Barrow, near the international station, under the direction of Lieut. P. H. Ray, U. S. Army, a shaft was sunk to a depth of 37 feet 6 inches, which passed through successive layers of mud, sand, and fine gravel, with fragments of driftwood and marine shells, showing here and there large fragments of pure fresh-water ice, but no continuous stratum of ice. The formation here was clearly a beach alluvium, and relatively modern, a pair of Eskimo wooden snow goggles with sinew string still attached to them being found at a depth of 27½ feet. The temperature of the earth varied from -5° to $+17.5^{\circ}$ F.; below the influence of the external air the temperature of the earth was quite steady at 12° F. for nine months. The earth was frozen and was extremely hard and tough. Blasts put into the side of the shaft blew out without shattering the frozen earth around the drill hole. It is probable that excavations farther inland might have revealed the ice layer, which at the locality of the station did not exist."

The observations made by the writer, while boating along the coast, lead to the inference that the ground ice is not of so widespread occurrence as the above quotation indicates. Between the Colville and Point Barrow the ice is possibly more or less continuous along the coast, but of its inland extension we have little evidence. Even along the coast it is not extensively exposed. Here long stretches of the low tundra country are apparently underlain by rock or earthy deposit.

Of the localities at which the ice was observed, the most important are Cape Halkett and Cape Simpson, at each of which it seems to be practically continuous for a distance of several miles. Cape Halkett, one of the most prominent promontories along this part of the coast (Pl. X, *D*), terminates in an ice cliff rising 30 feet above tide level, and is overlain by a foot or two of muck, which in turn is carpeted by a nap of moss and grass at the surface. Judging from topography, the ice at this locality may extend inland several miles. Its thickness is not known, since its lower limit lies below tide level. As shown in the view (Pl. X, *D*), the cape is being rapidly cut back by wave action, which undermines the cliff at tide level until by its own weight the ice breaks off in large blocks and is ground up by the surf.

Coal occurs at Wainwright Inlet, between Point Barrow and Cape Beaufort. A little southwest of that place the Jura-Cretaceous comes to the coast, and, judging from topography, seems to continue nearly all the way to Cape Beaufort, omitting a probable breach at Icy Cape. From Cape Beaufort to Cape Lisburne rocks of the Corwin series (Mesozoic) are known to be almost continuous. It therefore seems, from the above facts, that the southern boundary of the ground-ice area represented on Doctor Dall's map should be shifted from the region of Icy Cape northward, probably to at least beyond Wainwright Inlet, a distance of 60 to 75 miles.

Of the Kowak clay containing Pleistocene vertebrate remains, referred to by Doctor Dall in connection with the ground ice, but little was seen by the writer. Observation, however, has been sufficient to suggest that, if present along the coast

between the Colville and Chipp (Ikpikpuk) River, they are not only far from continuous, but are probably of very limited occurrence. Along the northwest part of the coast, the only locality at which what seems with certainty to be the Kowak clay was observed, is at Woody Inlet, about 50 miles southwest of Point Barrow. As this inlet is not far from the seventy-first degree of north latitude it is thought that the deposit may be near that in which Captain Beechey's party obtained elephant remains.

GUBIK SAND.

Besides the Tertiary Colville series, which underlies the coastal plain along Colville River, the section here also comprises deposits supposed to be Pleistocene. Of these, probably the most important and interesting is a surficial deposit of brownish sand or loam about 10 to 15 feet in thickness, which unconformably overlies the beds of the Colville series, apparently as a continuous mantle.

This deposit seems to be distinct from the Colville series and to extend over a large area of country. It not only forms the surficial terrane of the coastal plain along the Colville, but seems to occur at some localities along the coast from the mouth of the Colville westward, in some instances apparently overlying the ground ice and probably the Kowak clay formation, while its inland margin probably overlaps the coastal edge of the Upper Cretaceous of the Nanushuk series along the Anaktuvuk nearly to the mouth of the Tuluga, where, in certain localities, judging from topographic criteria, it also appears to overlie gravels which are very tentatively referred to as glacial, but to which its relation is not definitely known.

The deposit consists of fine sand, with apparently an admixture of considerable silt. In some localities it seems to be more sandy toward the base, and more earthy toward the top, where it terminates in from one to several feet of dark brown or black humus, clothed at the surface with moss and a little grass. It is ordinarily free from gravel, but in several instances subangular cherty pebbles ranging from mere sand grains to fragments as large as one-fourth inch in diameter were found. These occur very scatteringly and are sometimes roughened, as if wind worn. In some localities a fine gravel seems to intervene between the base of the deposit and the underlying Tertiary beds, as if representing the basal part of the deposit.

The deposit as a rule is structureless or without stratification planes. Owing to this fact, together with its surficial and widespread occurrence, and the homogeneity of its materials for want of a better term in field work it was called loess, but in the fear that this term may be undesirable, it is here named the Gubik sand, after the Eskimo name of Colville River.

Various hypotheses have suggested themselves to account for the origin of the deposit, of which no one alone seems to be satisfactory. To the writer, the fluvial delta theory, in conjunction with shallow coastal conditions and intense arctic freezing, seems the most tenable.

RECENT MUD, MUCK, GROUND ICE, DUNE SAND, SILTS, AND GRAVELS.

INLAND REGION.

The deposits mentioned in this heading are all represented on the map by the same color.

Along John River and the Koyukuk the color represents recent stream gravels, together with alluvial sands, silt with ground ice, mud flats, and areas of till too small to be represented on the scale of the accompanying map.

Along Anaktuvuk River the color denotes recent stream gravels, while along Colville River it includes, besides the recent stream gravels, a large, triangular area of flats extending from the mouth of the Anaktuvuk to the coast and eastward along the coast a distance of thirty or more miles to beyond Gwydyr Bay. This large area, as noted, is regarded as ground abandoned by the Colville in its lateral migration westward since Tertiary time, as the river is supposed to have formerly flowed more directly northeastward from the mouth of the Anaktuvuk, and to have entered the sea through Gwydyr Bay, following the course indicated by the broken lines on the map. (Pl. III.)

Though to the eye this area of flats seems a dead level the surface probably rises very gently from the Colville eastward. It is dotted by numerous ponds and lakelets. The monotony of the waste is somewhat relieved by occasional low mounds, as shown in Pl. XVI, *B*. These are composed, in part at least, of gravel and sand. Some of them rise as much as 40 feet above the flats. In shape they are low and rounded. Some have a tapering train on the lee side toward the coast. Their surface is usually scantily clothed with grass and other vegetation.

The origin of the mounds is not known. Only one of them was visited. Perhaps the most plausible hypothesis is that they are remnants of beds belonging to the Tertiary Colville series, which, chancing to be capped with some hard stratum, were not worn down by the river to the level of the flats, and so formed nuclei favorable for accumulation of gravel, and subsequently became bars, and, later still, islands in the Colville, until the river abandoned its bed about their bases.

Along the Colville the edge of the flats often terminates in gravel bars, descending to the water's edge, or in low, steep-faced banks of frozen black muck and ground ice, showing that at least the surficial portion of the flats consists in the main of recent stream deposits and the decayed products of marsh vegetation. The banks decrease in height toward the coast, and finally vanish as the land surface passes into the bars, reefs, and tidal mud flats at sea level.

The geologic work now being done by the river in its lateral migration shows that the processes by which the flats were formed were essentially those of planation. In the inland region, as the shifting stream, in its very gradual down-cutting and relatively very rapid lateral cutting, sawed its way westward into the coastal plain, it

planated farther and farther on the west the ground which by its destructional work it claimed as its bed; while simultaneously, as it abandoned or receded from this planated ground on the east, it built thereon, notably at high-water stages, flood-plain and riparian deposits, which now constitute the surficial terrane of the flats. Thus, while degradation or destructional work was in progress on the west, aggradation or constructional work of flood-plain building was progressing on the east. At the same time in the coastal region the large amount of sediments borne down by the river was built into an expansive delta plain, which landward merges into and is continuous with the inland subareal portion of the flats, and seaward merges into the already mentioned expansive tidal mud flats, bars, and reefs at the coast.

The Colville Flats therefore appear to consist essentially of a Pleistocene veneer of flood-plain, ground-ice, and deltoid deposits resting on Tertiary beds of the Colville series that have been planated by the river in its lateral migration toward the west.

Another type of recent deposits is seen in the sand dunes that occur for a distance of a few miles along the upper part of the Anaktuvuk, just before it leaves the Endicott Mountains, and also over the inland portion of the Colville delta and adjacent mainland. The material of the dunes in both places is obviously river sand and silts derived from the wind-swept bars and flats exposed during stages of low water. This dune work is probably accomplished mostly during the dry, frozen periods of winter, when the bare ice surface is favorable for wind transportation of the material.

COASTAL REGION.

From Colville River to Point Barrow.—Though the Tertiary beds of the Colville series may come to the Arctic coast in some localities, they have not been positively identified there. From Colville River to Point Barrow the shore line materials consist mainly of recent beach deposits of mud, muck, some sand and gravel, and deltoid mud flats, backed in places by low banks of older dark muck and ground ice (see Pl. IX, A and Pl. X, D). West of the Colville, in Harrison Bay, deposits of sand or loam are occasionally seen, which, from similarity in character of material, seem to belong to the Gubik sand.

The eastward swing, or retreat, of Colville River in relatively recent time from bluffs of its own cutting on the west, leaving a portion of the Colville Flats on its west or left side, along the section extending from Ocean Point to the coast, a distance of nearly 40 miles, suggests for this particular part of the region a local tilt to the eastward in Pleistocene time, or at least subsequent to the production of the bluffs and the Colville Flats, which must have been formed by the river. If this tilt or differential uplift to the west of the Colville has been far-reaching in its westward extent, it favors the existence of a coastal belt of late Pleistocene as far as it extends.

To local differentials in elevation along this costal line of uplift are to be ascribed the occasional ground-ice cliffs as at Cape Halkett and Cape Simpson, alternating with

long stretches of low shelving beach. The ice cliffs appear merely to represent completely solidified bays, lagoons, lakelets, or perhaps other coastal bodies of ponded water now raised into low anticlines and cut back by wave action.

From Point Barrow to Cape Lisburne.—Southwest of Point Barrow the coast line grows more marked. It is not so low, flat, and shelving as on the north, and the water is consequently less shoal. Here the long stretches of mud flats found on the north are in the main wanting. The mainland bluffs at the edge of the tundra, though still low, are not only higher than on the north but are almost continuous, and are frequently composed of true bed rock (Mesozoic terranes); between the base of these bluffs and tide water there is a narrow fringe of recent beach gravels and sand, whose surface slopes steeply seaward. However, from Wainwright Inlet to near Cape Beaufort there are extensive wave-built barrier beaches or bars of recent marine gravels and sand (see Pl. XVI, A), sheltering immense stretches of brackish lagoons lying between the bars and the mainland. Toward Cape Lisburne, the most bold and important promontory in this part of the northwest, the coast becomes steep and rock bound (Pl. V) by the Mesozoics and Paleozoics that have been described.

RECENT FOSSILS FROM THE ARCTIC COAST.

The following invertebrate fossils were collected along the Arctic coast between Colville River and Cape Lisburne. The identifications are by Dr. W. H. Dall, of the United States Geological Survey.

- Chrysodomus fornicatus* Gray, 649,^a 650, 654.
- C. despectus* L., 639.
- Admete couthouyi* Jay, 652.
- Margarites striatus* Sowerby, 647.
- Tellina lutea* Gray, 647.
- Macoma frigida* Hanley, 636, 639, 647, 650.
- M. tenuis* Leach, 639, 652.
- M. baltica* var. *inconspicua* B. & S., 636.
- Astarte arctica* Gray, 636, 639.
- A. borealis* Schumacher, 636, 639, 650, 652, 654.
- Venericardia alaskana* Dall, 652.
- Saxicava arctica* L., 650.
- Serripes grönlandicus* Beck, 636, 654.
- Cyrtodaria kürriana* (Mörch) Dunker, 639, 650.
- Thracia beringi* Dall, 654.
- Mytilus edulis* L., 650.
- Modiolaria nigra* Gray, 650.
- Yoldia* sp. *fragm.*, 639.

^a The numbers refer to localities.



A. BARRIER REEF AND ESKIMO GRAVE ON ARCTIC COAST NEAR ICY CAPE.
Looking S. 25° W.



B. ABANDONED PLEISTOCENE FLATS OF COLVILLE RIVER, SHOWING MOUNDS AND LAKELETS.
From 30 miles inland; looking N. 80° E.

TABLE OF PROVISIONAL CORRELATIONS.

Schrader: Chandlar and Koyukuk rivers, 1899. ^a		Mendelhall: Dall, Kanuti, Alatna, and Kowak rivers and Kotzebue Sound, 1901. ^b		Schrader: Chandlar, Koyukuk, John, Anaktuvuk, and Colville rivers and Arctic coast from Colville River via Point Barrow to near Cape Lisburne, 1901.	
Pleistocene.....	Stream silts and gravels.....	Silt, clays, sands, and gravels, including glacial deposits, Kowak clays and ground-ice formation.		Stream and beach gravels, mud (flats), sands, and silts.	
	Till and glacial gravels. Lacustrine silts of Yukon and Koyukuk flats.			Dune sands. Gubik sand.	
	Ground ice and Kowak (?) clays.			Till and glacial gravels. Ground ice and Kowak clay.	
	Basalts of Koyukuk Mountain and Chandlar River. Nulato sandstone ?.	Basalts, andesites, and andesitic breccias.		Upper Colville.	
Tertiary.....	Pliocene.....			Lower Colville.	
	Miocene.....			Nanushuk series.	
Cretaceous.....	Oligocene.....			Bergman series (?).	
	Eocene.....			Koyukuk series, including igneous rocks.	
	Upper.....			Anaktuvuk series.	
	Lower.....			Corwin series.	
Mesozoic.....	Jura-Cretaceous.....				
	Jurassic.....				
	Triassic.....				
	Carboniferous.....				
Paleozoic.....	Upper.....				
	Middle.....				
	Lower.....				
	Devonian.....				
Paleozoic.....	Upper.....				
	Middle.....				
	Lower.....				
	Silurian.....				
Paleozoic.....	Upper.....				
	Middle.....				
	Lower.....				
	Pre-Silurian.....				

^aSchrader, F. C., Reconnaissance along the Chandlar and Koyukuk rivers, Alaska: Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 2, 1900, pp. 471-482.
^bMendelhall, W. C., Reconnaissance from Fort Hamlin to Kotzebue Sound, Alaska, by way of Dall, Kanuti, Allen, and Kowak rivers: Prof. Paper U. S. Geol. Survey No. 10, 1902, pp. 31-48.

MINERAL RESOURCES.**GENERAL STATEMENT.**

Under the head of geology, it has been shown that the rocks forming the mountains about the head of the Koyukuk Basin comprise several metamorphic series, namely, the Skajit, Totsen, Fickett, Bettles, Lake quartz-schist, and West Fork series. In these mineralization has taken place. It is in the southern part of the region that the efforts of the prospector are being rewarded, and, in some cases, handsomely.

Though indications of mineralization occur to some extent nearly all the way northward through the Endicott Mountains, the principal producing region is on the upper parts of Middle and North forks of the Koyukuk. Though the region also contains coal and some lead, copper, and antimony, thus far gold only has proved to be of economic importance.

GOLD.

Placer gold has been known in the Koyukuk Basin since the early nineties, if not before. It was first discovered in the bars of the river, of which the most noted seem to have been Hughes and Florence bars, both far below the present placer diggings. Tramway Bar, above the sixty-seventh parallel, about 570 miles above the mouth of the river, is among the earliest discoveries. The discovery of Slate, Myrtle, and the other creeks that have been among the chief producers for the last four years was made during and subsequent to the spring of 1899. These are mostly above Tramway Bar.

Roughly considered, the Koyukuk gold district, or gold diggings, frequently referred to as the most northern mining camp in the world, as known at present is contained in a rectangular area of about 3,500 square miles, lying between latitudes $66^{\circ} 55'$ and $67^{\circ} 55'$ and longitudes $149^{\circ} 30'$ and $151^{\circ} 20'$.^a It accordingly trends north and south. Its length is about 70 miles and its width about 50 miles. Diagonally through it from northeast to southwest flows Middle Fork of Koyukuk River, while the northwest portion is drained by North Fork and the southeast portion by South Fork. The principal field of present operations is near the middle of the district, on the middle drainages of Middle and North forks.

It is only in certain localities in this area, however, that profitable gold placers have been found. The formations on which these placers lie, so far as known, are the Lake quartz-schist, the West Fork schist, the Bergman series, and probably also the Skajit formation, for some of the later discoveries are reported to occur on mica-schist, limestone, and marble;^b but whether any or all of these formations are the original source or mother rock of the gold can not yet definitely be stated, as the season's work afforded no facility for visiting the diggings. The Slate Creek

^a For location and outline of the district, see geologic map, Pl. III.

^b On Clara and Emma creeks the country rock is reported to be mica-schist and marble.

gold, however, is probably derived from the Lake quartz-schist.^a These schists are traversed by quartz veins of considerable size, the larger of which are not known to carry more than a trace of gold, but a series of smaller veins or veinlets and small lenticular quartz bodies or leaflets contained in the schist are to some extent auriferous. Nearly all quartz specimens which have been assayed show at least a trace of gold.

The principal diggings when the region was visited by the writer in 1899 were those of Slate Creek and Myrtle Creek, which lie along the zone where the Lake quartzite-schist gives way to the West Fork^b series on the south. This zone is also along the line where the mountains give way to the dissected supposed Yukon Plateau. Here in March, 1899, coarse placer gold was discovered in paying quantities on Slate Creek, an east side tributary of Middle Fork of the Koyukuk, which it joins 16 miles above Tramway Bar. The country rock is a series composed of mica-schist, quartz-schist, and slate, and is cut by some igneous intrusives. It is uplifted and stands on edge. The gold occurs as shallow creek and gulch diggings, and is found principally near or on bed rock in joints, fissures, and crevices. The gravels rarely exceed 3½ feet in thickness. The diggings begin about 9 miles above the mouth of Slate Creek, at the confluence of the two main forks, of which the north one is known as Myrtle Creek, and the south one as Slate Creek proper. From this point the diggings extend to the head of Myrtle Creek, a distance of 5 or 6 miles, and considerably farther up Slate Creek.

Two mining districts had been organized and are known as the Slate Creek and Myrtle Creek districts. The gold, as seen here, is bright, clean looking, coarse, and considerably rolled or flattened, denoting transportation. The largest nugget taken out had a value of nearly \$20. The bench gravels along these creeks are also auriferous and are reported to prospect from 3 to 5 cents per pan. Considerable mining was also being done near the sixty-seventh parallel on various tributaries of South Fork with fair success; here at present the principal camp is that of Gold Bench.

Though the Slate and Myrtle creek districts, with a few others, are reported to have yielded well during the season of 1899 and 1900, and are still producing, subsequent exploitation has resulted in the discovery of much richer deposits farther up the river, all occurring, according to reports of the miners, in much the same class of metamorphic rocks as those noted for Slate and Myrtle creeks.

Of these newer discoveries, the principal are Emma, Clara, and Gold creeks, and other smaller streams tributary to Hammond Creek, while the discovery of gold on Union Gulch, about 15 miles above Slate Creek, is reported to have been made

^aSchrader, F. C., Reconnaissance along the Chandlar and Koyukuk rivers, Alaska, in 1899: Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 2, 1900, pp. 474-483.

^bIbid., p. 475.

during the summer of 1901. Other new creeks, reported to be producing, are Vermont, Swift, and Nolan. The two best producers thus far are reported to be Emma and Gold creeks. The gravels on Hammond Creek are reported to contain much iron pyrites, which, in sluicing, rapidly fills up the riffles, and in some specimens visibly exhibits embedded bodies and particles of free gold—a fact of no small economic importance, as it seems to point very strongly to deposits of gold-bearing pyrites or ore probably present within the Hammond Creek Basin as the source of the gold. During the summer of 1902 very promising prospects were discovered also on North Fork of the Koyukuk about 35 miles above its mouth. Here the belt containing gold-bearing gravels, locally considered, is said to have a width of about 20 miles and to trend in a general east-west direction about parallel with the mountains. The principal streams on the Fork are Mascot, Washington, and Big Four creeks. The discovery was made on Washington Creek in August, but the principal producer seems to be Mascot, a west-side tributary, which was discovered in September (1902), and during the season of 1903 yielded nearly \$100,000 in gold. This gold is coarse. It contains several \$100 nuggets, and other large ones of less value. The gravels are shallow; they range from a few inches to several feet in thickness, and contain a little black sand. Their shallowness enables the ground to be worked at a profit of about 70 per cent of the yield, which is much greater than that in most of the creeks of the Koyukuk district. The gold is found mostly on bed rock and in the extreme basal part of the overlying gravels, and where the bed rock is rotten or decayed the gold frequently extends a foot or more into it. The bed rock is mica-schist. It contains stringers of quartz and is occasionally cut by porphyry dikes. Gold prospects have also been found west of the above, on tributaries of the Hokotena.

The Tramway Bar diggings are bench placers, consisting apparently of deposits of auriferous river gravels resting on a bench of bed-rock conglomerate and sandstone, at about 80 to 100 feet above the level of the river. The gravels are mostly coarse, consisting largely of rolled cobbles and pebbles of quartz-schist and other rocks composing the mountains to the north. Several attempts have been made to work these deposits, but thus far with only moderate success. This is owing apparently to the remoteness of the region, the difficulty of transportation, and more especially to the lack of capital to utilize the water supply, which could readily be drawn from the river above the placers or from lakelets said to occur on higher ground lying westward.

The Tramway conglomerate has not as yet been found to be a fossil placer, as was formerly supposed, nor does it seem to bear any relations to the richer diggings occurring in the region of metamorphic rocks much farther up the river.

Prospects of gold are also reported to have been found on some of the tributaries

of John River. Colors were obtained here by the writer from gravels in the mouth of a small creek near the north edge of the Totsen series, and specimens of vein quartz collected in place from sandstone and schist near the middle of the Fickett series assayed 0.03 ounce, or about 60 cents per ton. Though this may not be promising from an economic point of view, it seems to denote the presence of gold in the Endicott Mountains and points to the quartz as its probable source.

Coarse placer gold is reported to have been found by prospectors on the Arctic side of the divide, opposite the head of the Koyukuk Basin and farther eastward. Further investigations are contemplated here by men who have visited the region. This reported occurrence suggests the northward continuation of the auriferous schists of the Koyukuk district.

So far as observed by the writer, and learned from the accounts of prospectors, some of whose observations in the district have been extensive, the Koyukuk diggings in general are shallow, the gravels being but a few feet thick. Owing to this fact the placers are essentially what is known as summer diggings. Burning and drifting have been tried, but with only moderate success. About the only streams on which any winter work was done during the winter of 1902-3 are Hammond and Gold creeks. The richest placers are those in the creek beds and gulches; but gold-bearing gravels, sometimes of promising grade, occur also at higher elevations on the benches. Much of the gold occurs in the bed-rock cavities or in joint and cleavage crevices. It is coarse, much flattened, and ranges in size from that of a lima bean down to small grains. It is of high grade, being much purer than most of the Alaskan placer gold, and runs from \$19 to \$19.60 per ounce.

An exception to the flattened form of the gold occurs at Gold Bench on South Fork. Here the principal diggings are on a gently sloping bench at from 30 to 60 feet above the stream. On the bench the gold is all flattened, similar to that of the Koyukuk district in general, and is nearly all found within 8 to 10 feet of the surface. At the foot of the bench, however, the gold found in the high-water gravels of the present stream is of totally different character. It is not flat and smooth, but is round or angular, some particles being so sharply angular, rough, and honeycombed as to suggest little, if any, transportation since it was released from the mother rock.

Coarser gold than has been mentioned in the preceding paragraphs has also been found at various localities in the Koyukuk district. The largest piece found in 1900 is an 18-ounce nugget, having a money value of about \$350, and is reported to be from Clara Creek. The largest found during the season of 1901 is a \$660 nugget, said to have come from Union Gulch. In 1902 a much larger nugget, having a money value of about \$1,100, was brought out. It is reported to have been found on Hammond Creek. This nugget was seen by the writer. It is flat, oblong in outline, having somewhat the shape of a man's hand. It consists of almost pure gold,

very little quartz being present. It presents a clean, bright surface and is of a deep, rich color. Another nugget, nearly as large as the above, having a weight of 50 ounces and valued at about \$1,000, was found on Hammond Creek during the same year, but was not brought out of the country until this fall (1903). It is described by Mr. Prindle as oblong and elongated in outline, flat on one side and rounded on the other.

According to the most reliable information obtained, the production of the Koyukuk district from 1899 to 1903 was about \$717,000, distributed among the various creeks and gulches, principally as follows:

Production of gold in the Koyukuk district from 1900 to 1903.

	1900.	1901.	1902.	1903.
Myrtle Creek	\$40,000	\$7,000	.....	.....
Gold Bench	25,000	60,000	.....	.....
Slate Creek	1,000?	.....	.....	.....
Emma Creek	27,000	40,000	.....	.....
Clara Creek	1,000	2,000	.....	.....
Gold Creek	2,000	50,000	.....	.....
Tramway Bar	5,000	.....	.....	.....
Twelvemile Creek	1,000	1,500	.....	.....
Porcupine Creek	500	1,000	.....	.....
Ironside Bench and Eagle Bluff	1,000	.....	.....	.....
California Creek .....	.....	1,000	.....	.....
Union Gulch .....	.....	1,500	.....	.....
Total	103,500	164,000	^a 100,000	^b 300,000

^a Season's yield, including new discoveries. ^b Season's yield, including North Fork and new discoveries.

The total of the above table is \$667,500. To this should be added \$40,000, which is known to be the approximate output of sundry smaller diggings, not given in the above list in 1901; about \$6,000 output in 1899 derived mostly from Slate and Myrtle creeks and various points on South Fork, and \$3,000 to \$4,000 won from the Tramway and other bars in previous years, all of which to date gives an aggregate yield for the Koyukuk district of about \$717,000.

The relatively low yield, not much exceeding \$100,000 for the year 1902, is reported to be due to the exceptional dryness of the season and consequent lack of water for operations on most of the creeks. On Gold Creek but little sluicing could be done, but while the water lasted the yield was rich. On one claim the owners are reported to have washed out \$12,000 in ten days.

In connection with the above statement concerning gold should be mentioned the reported recent discovery of supposedly promising pyritiferous gold-bearing ore near the head of Alatna River, principally on the divide between it and Noatak River, which flows westward into Kotzebue Sound. The locality is northwest of Bergman, in approximate latitude 67° 40', longitude 155°. The men who made the discovery state that the locality is 170 miles from Bergman, but this must be by the river route where the distance traveled is necessarily greatly increased by the very

tortuous course of the Alatna. Our knowledge concerning the geography of this region is not definite, but the distance across country in a straight line from Bergman to the Koyukuk can hardly exceed 100 miles, and it is probably less.

The discovery seems to have been made by a party of prospectors and miners who visited the region by sled during the winter of 1902-3, and in company with others continued to prospect there during the summer of 1903. At present a score or more men are reported to be interested in the holdings.

The country rock is described as quartzite, slate, and schist, and is inferred by the writer to be in all probability a westward extension of the Fickett series (Carboniferous) which is prominently developed on John River, 60 miles distant, and in which, as indicated on the map (Pl. III) and on page 106, a mineralized zone in the slate and quartzite was observed by the writer in 1901. Without here affirming that the mineral deposits of these two regions are connected, it should be noted that the newly discovered Alatna deposits seem to lie directly in the trend of the John River deposits and have the same strike. This suggests that the deposits of the two regions may represent the same mineral belt.

The Alatna ore deposits are reported to consist of six or more veins, or ledges, known as the Copper King, Copper Queen, Lucky Six, Mammoth, Iowa, Gray Eagle, Silver King, and Ground Hog. They are on an average about 1 mile apart, and are accordingly included in a belt about 6 or 7 miles in width. They lie nearly parallel and trend in a northeast-southwesterly direction, and, so far as prospected, are in general nearly vertical, or dip about 75° NW.

About half of the veins are reported to have a width of approximately 75 feet, while the minimum width of the smallest is given as 10 feet. Some of the veins have been traced by croppings for distances varying from several thousand feet to 2 miles.

Through the courtesy of Mr. Prindle the writer has received for study six of these Alatna ore specimens, brought out by the miners in the fall of 1903. In these specimens the ore consists essentially of iron pyrites and quartz, with also chalcopyrite (copper pyrites) which is conspicuous in two specimens. With the chalcopyrite is associated a little bornite and a trace of malachite. Another specimen is composed essentially of stibnite or sulphide of antimony and epidote. One specimen contains feldspar as a gangue mineral in addition to quartz, and is locally stained reddish brown by hematite or iron oxide, which is seemingly an alteration product of the pyrites.

The quartz is largely of the finely granular sugary type, and often remains as a porous honeycombed or coralline-like mass where the metallic contents of the ore have been leached out of the more exposed croppings. This "skeletonized" mass is occasionally traversed by small discontinuous stringers of firmer, greasy-lustered, and evidently younger quartz, producing a semibanded appearance, which,

considered in connection with slickensiding and planes of weakness exhibited by other specimens, shows that ore deposition was followed by rock movement and consequent crushing, which produced fractures, into which the barren stringers were subsequently deposited by silica-charged solutions.

The specimens at hand contain both white and yellow iron pyrites, which is mostly fine-grained and normally occurs massive with the quartz, but in a few cases an imperfect parallelism, or banding, apparently representing depositional layers of quartz and pyrites in varying amounts, is perceptible.

The value of the ore rests in its auriferous content. At least three of the larger veins are reported, from assays made for the owners in San Francisco, to carry from \$40 to \$90 per ton in gold.^a The gold seems to be contained, very finely disseminated, in the pyrites, for so far as known no free gold is visible. None was seen in the specimens examined by the writer.

Should these deposits prove to be of economic value, it is noteworthy that besides being easily accessible by land, they can be approached at high water by way of the Alatna River with flat-bottom steamboat to a point within 6 miles of the locality, and at low water to a point within 20 miles. The region is reported to contain a large amount of small timber having a stumpage of about 1 foot in diameter.

COPPER.

The only indications of copper seen in this northern country by the writer were in detached fragments of quartz, apparently derived from veins, and carrying some iron pyrites, copper pyrites, malachite, and a trace of bornite. Such specimens were found sparingly in the river gravels on the upper Chandlar in 1899.^b Some, seen in the possession of prospectors, were reported to have been collected on Mineral Creek, at the head of Chandlar Lake, on the west side. A ledge is also reported to have been found on East Fork of the Chandlar, which assayed well in copper. But the ore is not known to occur in quantities of commercial value.

In the Koyukuk Basin the indications are much the same as above described, the occurrences being on the upper waters or the tributaries heading in the limestone mountains. The principal specimens seen by the writer during the recent work consisted of waterworn fragments found in the John River gravels and derived apparently from quartz veins. They contained some copper pyrites and a little bornite. Similar specimens were seen in the hands of Kowak natives on John River. What is supposed to be a vein of considerable size, containing iron and apparently copper pyrites, was observed in a steep limestone cliff of the Skajit formation overlooking the river, where no examination or collection could be made.

^a The Survey has just completed the assay of four of the above-described ore specimens, with the following results, in ounces per ton: Specimen B, gold 0.05; silver none. Specimens C and D, gold, trace; silver, trace. Specimen F, gold 0.10; silver, 0.08. These results are not promising.

^b Op. cit., p. 482.

LEAD.

Galena is known to occur in the Bettles limestone on the upper waters of the Chandlar and the Koyukuk. It is also reported on East Fork of the Chandlar. Specimens have been seen from Bettles River. Some reported to be from the upper part of Hokotena River or Wild Creek, which is the next large river above John River, were presented to the writer by Messrs. Windrick and Bettles. In one instance the Wild Creek galena is associated with, or partly incloses, quartz crystals five-eighths inch in diameter and an inch or more in length, while in another instance the associated quartz seems to be chalcedonic. The ledge occurs on Michigan Creek (the large east-side tributary of the Hokotena), 3 miles above its mouth, and is supposed to be in the Skajit formation. It is reported to be of considerable size. Those who have prospected it are hopeful that it may prove to be of economic value. It is reported to assay some silver and several dollars in gold per ton.

On the east side of the divide between Middle Fork and South Fork, opposite the head of Minnie Creek, a limestone mountain of considerable size is reported by prospectors, in which galena is said to occur in large quantity.

ANTIMONY.

Pebbles and angular fragments of antimony sulphide, sometimes several inches in diameter, are found in the gravels of Gold Creek. A specimen of this mineral was determined in the chemical laboratory of the Survey to be a good grade of relatively pure stibnite. It is traversed by quartz stringers. Judging from the resemblance of the quartz to that seen in the Lake quartz-schists and the locality at which the antimony occurs it is inferred that this rock is probably the source of the ore.

Owing to the remoteness of the region the copper, lead, and antimony ores are not in themselves likely to prove of economic value unless the deposits are very exceptional in quantity and character.

ZONES OF METALLIFEROUS MINERALIZATION.

In the Totsen series.—About 40 miles above the mouth of John River, near the northern edge of the Totsen series, as shown on the geologic map (Pl. III), the mica-schists, in an area several miles wide trending northeast and southwest, across the valley, are stained a pronounced reddish-brown or hematite color, denoting apparently a zone in which iron pyrites and other sulphides occur more or less abundantly in the schist. Though the rock could not be examined in detail, it seems probable that the stain is due to iron oxide derived from the sulphides by oxidation. The residuary soil formed by the disintegration of the schist in this belt is not nearly so red as the rock itself, but is rather of a yellow-ocher or limonite color, which seems to be due to more extensive oxidation and weathering or to leaching out of the mineral matter.

In the Fickett series.—Toward the northern edge of the Fickett series, east of John River, in the Fork Peak region, where the country rock consists of heavy-bedded gray and pinkish quartzite and slate, there is a belt about 2 miles wide which is stained bright reddish brown, purple, and some other colors. As shown on the map, this belt also trends northeastward a distance of apparently about 15 miles to a point where the Fickett series gives way to the Lisburne formation. It seems also to extend southwestward beyond John River, but in that direction it is apparently not so conspicuous.

Here again the stain, which is surficial, is due to iron pyrites acted on by the process of weathering. A fresh fracture surface in hand specimen shows the zone of stain or weathering to be nearly always definitely marked, but in its penetration of the rock it may vary in different cases from a mere film to a zone nearly one-fourth inch in thickness. As the rock is known to contain iron pyrites very finely disseminated, and all of the five stained specimens tested by the chemical laboratory were found to contain ferric oxide (Fe_2O_3), with some sulphuric oxide (SO_3) present in four cases, the stain seems undoubtedly to be iron oxide derived from the pyrites by process of weathering. The brilliant peacock or bornite color, which by the inexperienced prospector would readily be mistaken for indications of copper, is iridescent hematite. The specimen in which no sulphuric oxide occurs was found to contain also siderite (FeCO_3).

Whether these zones of mineralization may prove to be of economic value can not be affirmed at present, as the rapid progress of the party through the country did not permit opportunity for examination. It may be noted, however, that both zones are closely related to formational boundaries, the southern being near the unconformable and probably deformational contact of the Totsen series with the Skajit formation, while the northern lies along the fault contact of the Fickett series with the Stuver series and Lisburne formation; and both zones trend in a general way parallel with the dominant jointing or major structure of the mountain range. The localities at which placer gold claims have been staked by prospectors, and gold colors panned by the writer on John River, lie within the southern zone.

COAL.

GENERAL STATEMENT.

Coal in one form or another, and varying in age from Tertiary to possibly Carboniferous, is more or less widely distributed in northern Alaska. It occurs in the Koyukuk drainage on the south side of the mountains, in the plateau on the Anaktuvuk, in the coastal plain on the Colville, and on the northwestern coast, in what is commonly known as the Cape Lisburne region, at Wainwright Inlet, Cape Beaufort, and several points between Cape Beaufort and Cape Lisburne (Pl. V).

KOYUKUK REGION.

Koyukuk River.—On Koyukuk River, in what was formerly supposed to be the Kenai^a series, lignite and coaly material in small amount is common in the sandstone, grit, and especially in the conglomerate. The best occurrence is just above Tramway Bar, where there is a vein nearly 12 feet thick, of which the middle 9 or 10 feet seems to be relatively pure fuel. Its analysis is given under No. 187 in the table on page 114, which shows it to be a low grade of bituminous coal. There seems to be no reason why with development this vein should not prove serviceable for local use.

John River.—Coal detritus in considerable quantity and of a character to suggest the probable occurrence of coal of economic value somewhere in the region north of this locality was seen in the John River gravels near the base of the Endicott Mountains. This coal may apparently with safety be called a good grade of bituminous. It breaks with a conchoidal fracture and has a bright shiny or glossy black surface.

ARCTIC SLOPE.

Coal has been found also at several points on the Arctic slope, notably on Anaktuvuk and Colville rivers.

Anaktuvuk River.—Coal was first encountered by our party on the Anaktuvuk, in the east bank, about 5 miles above the mouth of Tuluga River, about 130 miles from the Arctic coast, in latitude $69^{\circ} 11'$, longitude $151^{\circ} 4'$. This coal is of Upper Cretaceous age, forming part of the Nanushuk series, from which the fossils at this locality were collected. As shown in Pl. XII, *B*, the rocks here dip steeply south, at an angle varying from about 80° to nearly vertical, and rise to a height of 100 or more feet above the river flats. The coal is conformable with the rocks of the series of which it forms members and occurs in several beds, each a foot or more thick. It is laminated parallel with the bedding, apparently denoting pressure. Though in the weathered state it has the appearance of lignite, it is shown by No. 607 in the table of analyses on page 114 to be a bituminous coal, having a fuel ratio of about 1.20. The quantity thus far observed, however, is hardly sufficient to lead to the belief that the bed will prove of economic value in so remote a region.

Colville River.—At about 30 miles north of the above locality and at a distance of 100 miles from the coast, on the Colville, in the region of the mouth of the Anaktuvuk, in latitude approximately $69^{\circ} 32'$, longitude $151^{\circ} 30'$, lignitic coal appears in considerable quantity. It is found in the Colville series, which underlies the Arctic Coastal Plain in this region, and here rises 200 feet above the river nearly to the surface of the plain, forming bluffs along the left or west side of the river for 10 miles both above and below the mouth of the Anaktuvuk. (See Pl. VIII.)

^a Schrader, F. C., Reconnaissance along Chandlar and Koyukuk rivers, Alaska: Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 2, 1900, pp. 477 and 485.

Here the coal is abundant and conspicuous. In the talus at the foot of the bluffs it is strewn about in detached blocks and boulders ranging from 1 to several feet in diameter. Its occurrence in place in the bluffs is for the most part in the lower half of the section, where it appears in half a dozen or more beds that are from 1 to 3 or more feet in thickness, and are conformable with the Colville series, of which they form members. The beds lie for the most part nearly horizontal or dip very gently northward, and are well exposed for a distance of probably 10 or more miles along the river. They are represented by the dark or black layers in Pl. VIII.

The associated rocks, of which a fuller description is given under the head of geology, consist in general of heavy beds of partially consolidated silt, soft shale, soft sandstone, very impure limestone, and intermediate types of deposits.

So far as observed in ascending the geologic section, the coal layers in most cases are underlain by a heavy bed of soft sandstone or shale 3 to 6 feet thick, with an intervening thin 6 to 8 inch layer of shaly under clay. The shale bed often contains fragmental lignitic plant remains.

As shown in the table of analysis (p. 114), where it is indicated by No. 620, the coal seems to be a good quality of lignite, with volatile matter 30.33 and fixed carbon 30.27. As the specimen was considerably weathered, it is probable that the analysis here given may fall somewhat short of representing the average efficiency of the coal. On several occasions the coal was used by the party in camp fires, and gave good satisfaction. It burned readily and yielded considerable heat.

The coal in general presents a dull-black appearance, and at first appears massive, but on closer observation is found to contain nearly horizontal, more or less discontinuous beds and thin layers of highly metamorphosed material, which is of a deeper black and has a somewhat high anthracitic luster. The main body of the coal seems to be composed largely of a mass of similarly well-metamorphosed, short, and glistening needles or spicules, variously compressed together in horizontal arrangement, presenting somewhat the appearance of an imperfect fibrous or woody structure.

From the known occurrence of such lignite and lignitic plant remains in the Kenai (Oligocene) elsewhere in Alaska, and from the position of this coal in the beds above the Upper Cretaceous and below fossil-bearing Pliocene beds, the coal is inferred to be Oligocene. The vegetable fragments collected from the shale beneath the coal were examined by Doctor Dall, who suggests that they are probably the needles of *Sequoia langsdorffii* or some related conifer. He also suggests that the mass of this coal is probably composed of the trunks of *Sequoia*.

From an economic point of view, it should be stated that this coal is probably not suitable for export or for steaming purposes, and, though it is abundant it is unlikely, from its remoteness, under present conditions of the country, to prove to be of value for local use. It is not difficult of access, however, and could readily be

brought to the coast on river barges by way of the Colville, and probably on river steamers at high water; or over a cheaply constructed railroad across the coastal plain. Owing to the shallowness of the coast, however, difficulty would probably be experienced in loading it on ocean vessels.

Judging from the report of Howard, and that of Reed, coal or lignite apparently occurs also on the headwaters of the Colville. Concerning the region above the native village of Etivolipar, in latitude approximately $68^{\circ} 20'$, longitude 156° , Mr. Howard makes the following statement:

"During the forenoon we passed a hill, about 500 feet in elevation, with outcrops of coal. On the sides of this hill beyond the coal were also found pieces of a substance called wood by the natives. It was hard, brittle, light brown in color, very light in weight, and burned readily, giving out quantities of gas. This material was scattered about in all shapes, sizes, and quantities."^a

Mr. Howard's visit to the region was a hasty overland trip made in the closed season when the ground was covered with snow and ice, and it embraced but a small section, probably 40 to 50 miles, of the Colville. That of Mr. Reed was made in the open season when conditions were most favorable for observing and making investigations. Mr. Reed, who, in company with Mr. Lucas, is reported to have explored and prospected along the river for a distance of 200 or more miles, mostly downstream from the mouth of the "Killik" (see p. 31 of this paper), likewise reports that thick veins of bituminous coal crop out in the sandstone formation along most of the creeks, and states that the coal was burned by his party also in their camp fires.

From the topographic description given by Messrs. Howard and Reed, and from the geographic position of the region, being practically on a line with, and about intermediate in distance between the Cape Beaufort and Corwin regions on the northwest coast, and that of the upper Anaktuvuk in the interior, at which points the rocks are known to be coal bearing, or at least of Mesozoic age, the writer infers the sandstone formation in which the coal or lignite occurs on the upper Colville to be in all probability Mesozoic, and possibly also like the Corwin series, Jura-Cretaceous. And since the Mesozoic coals of the Territory are usually a good grade of bituminous character, it would not be surprising to find the upper Colville region to contain fuel of substantial economic value, similar to the coal produced by the Corwin and Thetis mines on the northwest coast, next to be described.

NORTHWEST COAST.

Coal has been known in the vicinity of Cape Lisburne (see sketch map, Pl. V) for half a century, and since 1879 whaling vessels have replenished their supply from this locality. It occurs also at several places along the coast to the northeast as far

^aStoney, Lieut. George M., *Naval explorations in Alaska*, U. S. Naval Institute, Annapolis, Md., 1900.

as Wainwright Inlet, a distance of about 200 miles. It is not certain, however, that the beds at these various points represent the same coal field or even that they all occur in the same formation. Though these coals have been somewhat exploited, and numerous fossils, ranging from early Paleozoic to Mesozoic, have been reported from the region, no definite conclusion has been reached concerning the geologic age of the rocks in which the coals occur.

Wainwright Inlet.—The most northerly occurrence of the coal yet reported along this coast is at Wainwright Inlet, latitude $70^{\circ} 37'$, longitude $159^{\circ} 45'$. Here it is said by Mr. Woolfe,^a who discovered it in 1889, to occur on the banks of Koog River, which flows into the inlet. As the river is shallow at its mouth, flat-bottomed boats or lighters would be required for getting the coal to the sea. The coal is described by Mr. Woolfe "as being of better quality and containing less detritus than the Cape Lisburne mineral. It appears to be a light but hard lignite, burning briskly, with but little ash." It is somewhat surprising that this coal should excel the Cape Lisburne coal in fuel efficiency, as the latter is believed to be the older, more highly metamorphosed, and carbonized. Though the writer was not able to visit the Wainwright Inlet exposure, at a point about 20 miles southwest of the inlet paleontologic evidence showed the country rock to be probably Jura-Cretaceous (p. 74). Judging from topographic criteria, the same formation seems to extend beyond Wainwright Inlet. Samples of apparently good coal were found near the place where the fossils were collected. Analysis of one of these, however, No. 653 in the table (p. 114), shows that it is a lignite.

Though coal float is found in the beach gravels at several localities along the coast, actual outcrops of coal were not seen and are probably not numerous.

Cape Beaufort.—Cape Beaufort, in latitude about $69^{\circ} 10'$ and longitude $163^{\circ} 36'$ (see Pl. V), marks the coastal terminus of the line of demarcation between the very gently rolling or nearly flat lowland tundra country on the north and the more hilly and low mountainous region on the south which merges with mountains that terminate in Cape Lisburne. It lies about 70 miles northeast of Cape Lisburne. The term cape is hardly applicable to Beaufort, however, as there is here no real promontory, but only a ridge rising to a height of about 800 feet above the uniform shore line.

A 6-foot vein of coal occurs in the folded and faulted sandstone of this ridge. It is probably best exposed about one-eighth to one-fourth of a mile from the coast, whence it seems to extend farther inland and with care can probably also be traced to the coast. So far as observed, the vein dips gently southward with the rocks of the region. As shown in the table of analyses under No. 665, page 114, this is a good bituminous coal.

It may be well to note that Doctor Dall, in his report on Alaskan coal and

^a Report on population and resources of Alaska at the Eleventh Census, 1890, Washington, 1893, p. 133.

lignites, includes under the name of "Cape Beaufort coal measures" all the coal from near Cape Lisburne to Cape Beaufort, inclusive, covering a stretch of more than 40 miles in extent. As the coal throughout this region may possibly, on further investigation, all be found to be of the same geologic age, it may for the present fittingly be referred to under the one name. It should be remarked, however, that the vein at Cape Beaufort, which is the extreme northern limit of the field, is relatively little known, while that which is most familiar as the source of supply for the whalers is in the extreme southwestern part of the field. Doctor Dall's basis for thus including the coal of this entire region under one head is probably the description and extent of the occurrence of the coal given by Mr. Henry D. Woolfe, whose report, as condensed by Doctor Dall, is here quoted:^a

"Along the beach and coast line from Cape Lisburne for at least 40 miles an extensive and well-defined coal field exists. I was engaged for two seasons in exploiting these deposits. Research developed the existence of a body of coal extending over an area of 25 square miles. There are along the coast line for the distance mentioned numerous veins of coal from which the whalers obtain supplies of fuel. The coal is of the type of semibituminous lignite. It makes steam quickly, but there is a very large percentage of ash and clinker, and its constant use causes an early burning out of the furnace bars. * * * At present the whalers dig out their supplies from the surface veins, climbing the cliffs to obtain it. * * * With any wind, except from the coast or southeast, there is no protection on the coast mentioned, and the work of boating the coal off to a vessel lying at some distance from the shore is difficult, and in windy weather dangerous. With the ice pack offshore a lee is obtained which makes smooth water and facilitates coaling. The limit of the important coal-bearing area to the north is at Cape Beaufort, though small seams are seen farther on. Between the seams bands of clear ice intervene, and I have noticed on the shelving banks of a small creek that runs through the coal land an oily exudation resembling petroleum."

Until the past few years Mr. Woolfe had seen more of this coal field than any other man, and we are fortunate in having the benefit of his observations, though the field may not prove so large or rich as he inferred.

Thetis and Corwin mines.—Turning our attention to the southwestern and apparently most important part of the field, we find here the Thetis and Corwin coal mines, old supply points of the whalers and United States revenue vessels. These names, Thetis and Corwin, which have appeared on the charts for many years, are taken from vessels of the revenue service which replenished their coal bunkers at these mines on their annual cruises in the Arctic.

The Thetis mine is situated near the mouth of Thetis Creek and east of Cape Sabine, a low and unimportant promontory, shown in Pls. V and X, *C*. The coal here is said to occur in sandstone and shale.

^a Dall, W. H., Report on coal and lignite of Alaska: Seventeenth Ann. Rept. U. S. Geol. Survey, pt. 1, 1896, p. 820.
^b Ibid.

The Corwin mines, which at present seem to be by far the most important, accessible, and productive, are situated farther to the southwest, near the southwestern limit of the coal measures referred to by Dall, and about 30 miles east of Cape Lisburne (see Pl. V). Coal is reported to have been obtained here by the whaling vessels as early as 1879. Its occurrence, so far as observed, is in 10 or 12 beds, varying from 1 to 16 feet in thickness, all being apparently quite persistent. The edges of these beds are exposed for a distance of about three-eighths of a mile along the coast, which cuts them diagonally, forming a steep cliff that rises from 30 feet on the west to more than 100 feet above tide on the east, where it attains its maximum in a low prominence known as Corwin Bluff. The coal beds, conformable with the country rock in which they occur, strike N. 45° W. and dip southwestward at an angle of 36°, as shown in Pl. XIII, *B*; but eastward, in Corwin Bluff, where the rocks are more disturbed, the dip steepens.

The country rock in which the coal occurs, as shown in the above view, is sandstone, shale, and slate, and is probably Jura-Cretaceous. It is more fully described under the head of geology, page 72. As noted, it very much resembles the rocks of the Anaktuvuk series, but is supposed to be older.

Some of the coal in the Corwin mines has been partially crushed, but not greatly damaged, by rock movement. In mining much of it is taken out in large blocks, 1 to 2 or more feet in diameter, and nearly all of the beds are comparatively pure. Average samples collected by the writer gave the analyses under numbers 669 and 671 in the accompanying table, page 114, showing the product to be a bituminous coal of fair grade, with a fuel ratio of 1.10 and 1.30. It is, however, hardly satisfactory for blacksmithing or steaming purposes. It was used on the steamship *Arctic*, on which the party took passage for Nome, but with much the same results as indicated by Mr. Woolfe. Though it burns readily and produces steam quickly, it is of low specific gravity and not lasting. It takes about double the amount of this coal as compared with Comax coal to maintain a given steam pressure. It burns with little smoke, but produces a large amount of ash and clinker. This instance, however, can hardly be considered a fair trial, as, owing to the want of timber, the facilities for mining were so poor that much "bone," rock, and dirt, or foreign débris found its way into the coal and thence into the furnace. The coal is reported to be good for cooking and household purposes.

Mr. Charles L. Norton,^a of the Massachusetts Institute of Technology, is said to have made the following report to the Corwin Trading Company on "Cape Lisburne coal," which was probably collected at or in the region of the Corwin mines:

"I find that the specimens of Alaska coal which you recently sent me have a calorific power of 7,560 calories per gram. This is quite as good as the average western coal, and is not more than 10 per cent inferior to the best eastern coals."

^aBrooks, A. H., The coal resources of Alaska: Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 3, 1902, p. 566.

The Corwin mines were operated to some extent during the summer of 1901 by the Arctic Development Company, who disposed of the coal in the Nome market, mostly for domestic purposes, where it is said to readily command \$18 or \$20 per ton in competition with the Comax or Washington coal at \$25 per ton.

As it is only on the exposed edges of the veins in the face of the beach bluff that mining has thus far been carried on, it may be that the quality of the coal will improve somewhat with depth, but presumably not to an important extent, since at a distance of 10 to 15 feet below the surface the coal appears bright, firm, dry, and unweathered.

There is undoubtedly a large amount of coal in the region of the Corwin mines, but there are no harbor facilities. The beach is exposed to heavy surfs, much as it is at Nome, and the water is shallow, so that ocean vessels do not often approach within three-eighths of a mile of the shore. The coal is loaded aboard the vessels by lighters, as at Nome, which, as it can be accomplished only at periods of quiet weather or favorable wind, is, to say the least, expensive, uncertain, and tedious. A project of constructing an aerial tramway for loading purposes, from the bluff out to the anchorage of the vessels, is said to be under consideration.

The claims in the vicinity of the mines have been taken up, mostly by the Arctic Development Company of San Francisco, whose reported plan of future development work includes the sinking of a shaft on one of the large middle veins, and cross-cutting to the others.

Area south of Cape Lisburne.—Westward, toward Cape Lisburne, the Corwin series, in which the coals of the Thetis and Corwin mines occur, is supposed to give way to Paleozoic rocks, for the limestone cliffs 4 miles south of Cape Lisburne are known to contain Devonian corals and other forms. At about one-third of a mile north of this limestone locality, according to Mr. A. G. Maddren, who explored this section of the coast in 1900, there is a 4- to 5-foot vein of coal in shale, which dips north at an angle of 60°. This is at a point about one-third of a mile north of the coral limestone locality. This coal, Mr. Maddren thinks, is considerably older than that of the Corwin and Thetis localities. He reports:

“It is hard and breaks with a bright fracture. It was tried in the galley stove and gave a more intense fire than Nanaimo coal. The engineers said there was not enough underdraft beneath the main boiler to burn this coal fast enough for steaming purposes, that it was too hard and needed forced draft. The only point that seems to be against this coal is its lack of weight. It seems to have a low specific gravity, but this may be only at the surface, where it is leached out by the weather.”

The low specific gravity here mentioned would seem to place this coal in the same class with the Corwin coals, and suggests its possibly being a specimen somewhat more highly altered by metamorphism. Whether it is of greater geologic age than the Corwin, as supposed by Mr. Maddren, can not definitely be stated, but it

should be noted that in the shale associated with the coal there is reported to have been found by Mr. Dumars a small specimen of *Lepidodendron*, which has been determined by Mr. David White, who states that it is related to *Lepidodendron chemungense*, and that it indicates an age for the shale either of Upper Devonian or Lower Carboniferous.

Mr. Maddren also reports that in the valley between Cape Dyer and The Ears (shown in fig. 1) a syncline of shales occurs containing at least one exposure of coal along the low sea bluff that rises from 50 to 100 feet above tide. He also states that just south of Cape Lewis there is a bluff of shales that seem to contain "coal blossom."

ANALYSES OF COAL.

The following analyses were made by Mr. George Steiger, chemist of the Survey:

Table of coal analyses.

	187 Koyukuk River above Tramway Bar.	607 Anaktu- vuk River.	620 Colville River.	663 Wain- wright Inlet.	665 Cape Beaufort.	669 Corwin mines.	671 Corwin mines.	Cape Lisburne. ^a
Moisture	4. 47	6. 85	11. 50	10. 65	7. 18	10. 47	7. 23	3. 75
Volatile matter	34. 32	36. 39	30. 33	42. 99	36. 38	40. 12	38. 68	43. 75
Fixed carbon	48. 26	43. 38	30. 27	42. 94	51. 23	46. 16	50. 05	47. 39
Ash	12. 95	13. 38	27. 90	3. 42	5. 21	3. 25	4. 04	5. 11
	100. 00	100. 00	100. 00	100. 00	100. 00	100. 00	100. 00	100. 00
Sulphur		. 54	. 50	. 62	. 48	. 27	. 23	. 36
Phosphorus pentoxide		Trace.	Trace.	Trace.	Trace.	Trace.	Trace.	.....
Coke		None.	None.	None.	None.	None.	None.	.....
Fuel ratio	1. 40	1. 20	.....	.....	1. 4	1. 10	1. 30	1. 08

CLIMATIC CONDITIONS.

METEOROLOGIC RECORD FOR 1899.

The following is a record of meteorologic observations made by the writer on a reconnaissance along Chandlar and Koyukuk rivers in 1899, mainly in latitude 65° to 68°, longitude 145° to 158°. The localities at or near which they were made are designated by the position of the dates (month and day) on the map.^b

The thermometer used in this work is an H. Green, cylindrical bulb, Fahrenheit scale.

^a Brooks, A. H., The coal resources of Alaska: Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 3, 1902, p. 565.
^b Schrader, F. C., A reconnaissance along the Chandlar and Koyukuk rivers, Alaska, in 1899: Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 2, 1900, opposite p. 448.
The localities refer to camps pitched by the party en route at the close of its day's traverse. Hence the morning observation of any given date was usually made at the camp preceding the one of the date by which the observation is designated on the map, and the 2 p. m. observation of the same date was made at a point about midway between the two camps.

The meaning of the abbreviations used in the table to denote the kind and amount of clouds is as follows:

- A-cu =alto-cumulus.
- A-s =alto-stratus.
- Ci =cirrus.
- Ci-cu=cirro-cumulus.
- Ci-s =cirro-stratus.
- Cu =cumulus.
- Cu-n =cumulo-nimbus.
- N =nimbus.
- S =stratus.
- S-cu =strato-cumulus.
- 0 =clear sky.
- 1 =sky one-tenth cloudy.
- 5 =sky five-tenths or one-half cloudy.
- 10 =sky all cloudy.

The wind velocities here given were determined by estimate, but as some judgment had previously been acquired by the observer in forming estimates of wind velocity by noting the impressions it makes upon the person and the speed of light objects transported by it, and then comparing the estimates thus formed with the readings of standard anemometers, with which he had several years' experience, the estimates here given are believed to be approximately correct.

Since the barometric readings here given were made on an aneroid, where there were no field facilities for its comparison with a mercurial barometer, they purport to be of minor value only.

In the preparation of the table for publication, suggestions have been contributed by Dr. Cleveland Abbe, jr.

Meteorologic observations along Chandler and Koyukuk rivers essentially at 7 a. m. and 2 and 9 p. m., from June 19 to September 23, 1899.

Locality and date.	Tempera- ture.	Clouds: Kind and amount.	Wind: Direc- tion and velocity in miles per hour.	Barometer. (Aneroid.)	Weather.	Remarks.
Fort Yukon:	<i>Degr. F.</i>					
June 19.....	58 to 60	Cu. 9	High.	29.2	Blustery	
20, 2 p. m.	59	Cu. 8	High.	29.15	Blustery, showery	
21, 9 a. m.	58.9	Ci-cu. 3	Moderate.	29.1	Fine	
2 p. m.	64	Ci-cu. 5	Moderate.	29.15	do	
9 p. m.	63	Ci-cu. 8	0	29.14	do	
22, 7 a. m.	63.8	Ci-cu. 8	0	29.12	do	
Mouth of Chand- lar River:						
June 22, 2 p. m.	74.5	Ci-cu. 4	SW. 10.	29.16	do	
9 p. m.	56.6	Ci-cu. 7	0	29.1	Fair	
23, 7 a. m.	64.2	Ci-cu. 4	SW. 15.	29.07	Showery	
2 p. m.	63	Ci-cu. 3	SW. 15.	29.01	do	
9 p. m.	55	Ci-cu. 7	0	28.98	do	

Meteorologic observations along Chandlar and Koyukuk rivers essentially at 7 a. m. and 2 and 9 p. m., from June 19 to September 23, 1899—Continued.

Locality and date.	Temperature.	Clouds: Kind and amount.	Wind: Direction and velocity in miles per hour.	Barometer. (Aneroid.)	Weather.	Remarks.
Chandlar River:	Degr. F.					
June 24, 7 a. m.	52	Cl. 8	SW. 15.	28.98	Threatening.....	
2 p. m.	60	Cl. 2	SW. 15.	29.05	Bright and fine...	
9 p. m.	50	Cl. 4	SW. 20.	29.06	do	
25, 7 a. m.	51	Cl. 1	SW. 20.	29.15	do	
2 p. m.	55.6	Cl. 6	SW. 15.	29.15	do	
9 p. m.	54	Cl. 2	SW. 10.	29.16	do	
26, 7 a. m.	51	Cl. 1	SW. 5.	29.12	do	
2 p. m.	57.5	N. 9	SW. 4.	29.6	Showery and rain.	
9 p. m.	54.6	N. 8	SW. 15.	29.6	do	Temperature water, Chandlar River = 54.5°.
27, 7 a. m.	48	Cl. 1	SW. 20.	29.12	Bright	
2 p. m.	55	Cl-cu. 8	SW. 10.	29.1	Bright (?).....	(?).
9 p. m.	48	Cl-cu. 4	0	29.11	Bright	
28, 7 a. m.	53	Cl-cu. 2	SW. 2.	29.05	do	Two good showers last night.
2 p. m.	59.5	Threaten'g ..	SW. 3.	29.0	Showery	
9 p. m.	53	N. 10	NNW. 5.	28.9	do	Stormy on mountains.
29, 7 a. m.	54	N. 9	W. 5.	28.9	do	Do.
2 p. m.	59	Cu-S. 8	W. 2.	28.92	do	Mountains smoky; temperature river = 52°.
9 p. m.	52.5	N. 10	SW. 20.	28.8	Showery	Blustery.
30, 7 a. m.	44.5	Cu-n. 9	SW. 20.	28.8	do	Do.
2 p. m.	46.5	N. 10	SW. 15.	28.85	Steady rain	Showery all a. m.
9 p. m.	46.5	N. 10	SW. 10.	28.85	do	Rained all p. m.
July 1, 7 a. m.	44	N. 10	SW. 5.	29.8	do	Rainy all night.
2 p. m.	47	N-cu. 8	SW. 8.	29.06	Showery	Clearing (?).
9 p. m.	49	N-cu. 6	0	29.05	do	Do.
2, 7 a. m.	53	Cl-cu. 5	W. 20.	29.1	Bright	Temperature river = 49°.
2 p. m.	54	N. 8	SW. 30.	28.9	Showery	Showers.
9 p. m.	52	N. 7	SW. 20.	28.9	do	Do.
3, 7 a. m.	54	N. 3	SW. 20.	29.04	do	Blustery.
2 p. m.	57	Cl-cu. 2	SWW. 20.	29.1	Clear	Clear and fine; sunset at 10 p. m.
9 p. m.	49	Cl-cu. 1	S. 77° W. 1.	29.2	do	Clear and fine.
4, 7 a. m.	50	Cl. 2	S. 77° W. 5.	29.30	Bright; hazy	Hazy; bright.
2 p. m.	62.5	Cl. 3	S. 77° W. 20.	29.20	do	Threatening.
9 p. m.	55	N. 8	SW. 20.	29.0	Threatening.....	
5, 7 a. m.	56.5	Cl. 2	SW. 20.	28.90	Bright	Bright.
2 p. m.	58	Cl. 2	W. 30.	28.1	do	Bright. On lava butte at edge of mountains and Yukon flats.
9 p. m.	64	Cl. 3	W. 20.	28.9	do	Bright.
6, 7 a. m.	60.5	Cl-cu. 4	W. 20.	28.9	do	Bright; temperature river below Forks = 55°, 11 a. m.; temperature Lake Fork = 55.5, 11.30 a. m.
2 p. m.	66.5	N. cu. 8	W. 20.	28.7	do	Cloudy; temperature above Forks = 55.8, 12 m.
9 p. m.	56	.....	W. 1.	28.18	Heavy shower at 5 p. m.	Bright.
7, 7 a. m.	52	3	W. 10.	28.9	do	Hazy.
2 p. m.	65	0	W. 5.	28.8	do	Fine warm day.
9 p. m.	55	0	0	28.8	do	Do.
8, 7 a. m.	58	0	W. 2.	28.75	do	Fine warm morning.
2 p. m.	69	0	W. 10.	.....	.....do	Warm day; temperature river = 56°.

Meteorologic observations along Chandlar and Koyukuk rivers essentially at 7 a. m. and 2 and 9 p. m., from June 19 to September 23, 1899—Continued.

Locality and date.	Temperature.	Clouds: Kind and amount.	Wind: Direction and velocity in miles per hour.	Barometer. (Aneroid.)	Weather.	Remarks.
Chandlar River—Continued.	Degr. F.					
July 8, 9 p. m.	61.5	0.....	0	.....	.....	Warm day.
9, 7 a. m.	56	Hazy 9.....	0	.....	.....	Sultry.
2 p. m.	73.5	0.....	W. 20.	.....	.....	Clear.
9 p. m.	61	0.....	W. 2.	.....	.....	Do.
10, 7 a. m.	56.5	N. 10.....	0	.....	Showery.....	Dark and rainy.
2 p. m.	57	N. 9.....	W. 30.	.....	do	Location: Station 3 at 4,000' on Granite Creek.
9 p. m.	62.5	N. 9.....	W. 20.	.....	do	
11, 7 a. m.	53	N. cu. 8.....	SW. 20.	.....	do	Stormy and blustery.
2 p. m.	56	N. 10.....	SW. 10.	.....	do	Showery.
9 p. m.	50	N. 10.....	0	.....	do	Do.
12, 7 a. m.	49	N. 10.....	SW. 5.	.....	do	Showery; temperature river = 46.5°.
2 p. m.	55	N. 8.....	0	.....	do	Showery.
9 p. m.	52	Cl-s. 6.....	SW. 5.	.....	.....	Showery till 5 p. m.
13, 7 a. m.	53.5	Cl. 2.....	SW. 10.	.....	Bright and sunny.	
2 p. m.	54	Cl. 1.....	SW. 15.	.....	do	Temperature river = 49°.
9 p. m.	53.5	Cl. 1.....	SW. 2.	.....	do	
14, 7 a. m.	55.5	0.....	SW. 3.	.....	do	
2 p. m.	58	S. 4.....	SW. 10.	.....	do	
9 p. m.	59	N. 7.....	SW. 1.	.....	.....	
15, 7 a. m.	50	N. 10.....	0	.....	Raining steadily..	Rained during night.
2 p. m.	53	N. 10.....	0	.....	Raining	
9 p. m.	53	N. 10.....	0	.....	Showery.....	
16, 7 a. m.	51.5	N. 10.....	SW. 5.	.....	Raining	Rainy all night.
2 p. m.	54	N-cu. 8.....	SW. 15.	.....	Showery?.....	Temperature river = 45°.
9 p. m.	46.5	0.....	SW. 30.	.....	.....	
17, 7 a. m.	48	Cl-cu. 2.....	SW. 20.	.....	.....	Bright and sunny.
2 p. m.	54	2.....	SW. 10.	.....	.....	Do.
9 p. m.	48.5	N. 9.....	SW. 15.	.....	.....	Threatening.
18, 7 a. m.	46.5	N. 9.....	SW. 10.	.....	Rainy and foggy.	Rained during night.
2 p. m.	55	N. 9.....	SW. 5.	.....	Foggy	Temperature river = 45°.
9 p. m.	51	N. 10.....	SW. 10.	.....	Rainy and foggy.	
19, 7 a. m.	47	N. 9.....	SW. 6.	.....	.....	Dubious.
2 p. m.	53	N. 9.....	SW. 20.	.....	Threatening; showery.	Dubious. Location: Chandlar Lake.
9 p. m.	47	Cl-cu. 8.....	SW. 15.	.....	Dubious	Showery in p. m.
20, 7 a. m.	47	Cl-cu. 6.....	SW. 15.	.....	Clearing.....	Somewhat cloudy on mountains.
2 p. m.	54	Cl. 1.....	SW. 20.	.....	Bright.....	Very windy.
9 p. m.	44	Cl-cu. 3.....	SW. 5.	.....	.....	Cool.
21, 7 a. m.	48	Cl-cu. 5.....	SW. 10.	.....	Dull	Do.
2 p. m.	59	Cl-cu. 4.....	S. 10.	.....	Bright.....	Do.
9 p. m.	49	Cl. 9.....	.....	.....	do	Do.
22, 7 a. m.	59	0.....	0	.....	do	Warming.
2 p. m.	70	Cl. 2.....	SW. 2.	.....	do	Warm; temperature river = 50°.
9 p. m.	55	N. 5.....	0	.....	do	Cooling.
23, 7 a. m.	59	Cl. 5.....	SE. 10.	.....	do	Warming.
2 p. m.	67	Cl-cu. 2.....	NWW. 10.	.....	do	Comfortable.
9 p. m.	56	Cl-cu. 5.....	W. 5.	.....	do	Cooling.
24, 7 a. m.	51	0.....	SWW. 4.	.....	do	Warm.
2 p. m.	74	Cl-cu. 4.....	NEE. 4.	.....	do	Do.
9 p. m.	55	N. 7.....	NEE. 3.	.....	.....	Cooling.

Meteorologic observations along Chandler and Koyukuk rivers essentially at 7 a. m. and 2 and 9 p. m., from June 19 to September 23, 1899—Continued.

Locality and date.	Temperature.	Clouds: Kind and amount.	Wind: Direction and velocity in miles per hour.	Barometer. (Aneroid.)	Weather.	Remarks.
<i>Degr. F.</i>						
Chandler River—Continued.						
July 25, 7 a. m.	56	Cl-cu. 2	SWW. 5.		Bright	
2 p. m.	68	Cl. 1	SWW.			Fine, comfortable day.
9 p. m.	59.5	Cl-cu. 2	0			Do.
26, 7 a. m.	59.5	0	SWW.			Fine; somewhat hazy.
2 p. m.	71	0	SWW. 5.			Fine.
9 p. m.	55	0	0			Fine; moonlight.
27, 7 a. m.	61	Cl. 3	NW. 10.			Fine; warm.
2 p. m.	73	Cu-n. 5	NW. 15.		Showery about lake.	Do.
9 p. m.	60	Cu-n. 6	0		Showery in p. m.	Fine; comfortable.
28, 7 a. m.	60	Cu-n. 5	NW. 5.			Warming.
2 p. m.	61	Cl-cu. 3	NW. 15.			Fine day.
9 p. m.	46	0	NW. 5.			Do.
29, 7 a. m.	49	0	0			Warming.
2 p. m.	58	0	0			Location: Summit of Chandler-Koyukuk portage at 3,500'.
9 p. m.	48	0	0			
30, 7 a. m.	37	0	0			
2 p. m.	68	0	NW. 5.			
9 p. m.	50	Hazy	0			
31, 7 a. m.	41	Hazy	0			
2 p. m.	61	Hazy	0		Showery	
9 p. m.	52	N. 1.	0		Raining	
Aug. 1, 7 a. m.	51	Cl-cu. 5.	0		Rain in night	Clearing.
2 p. m.	74	Cl. 2	NW. 5.		Hazy; bright.	Fine.
9 p. m.	62	N. 6.	0			
Koyukuk River:						
Aug. 2, 7 a. m.	67	Cl-cu. 4.	NW. 5.		Hazy; bright.	Fair.
2 p. m.	74	Cl-cu. 6.	NW. 8.			Cooling.
9 p. m.	60	N. 7.	NW. 5.		Showery	Comfortable.
3, 7 a. m.	57	N. 10.	NW. 4.		Rained hard 49 minutes.	Rainy and foggy.
2 p. m.	52	N. 10.	0		Rainy	
9 p. m.	45	Cl-cu. 4.	W. 4.		Clearing	Clearing and cool.
4, 7 a. m.	52	0	W. 4.			Warming fast (?).
2 p. m.	46	S. 3.	SW. 7.			Cold. Location: Mount Horace at 5,600'.
9 p. m.	45	Cu-n. 5	0			Do.
5, 7 a. m.	54	Cu. 4.	0			Heavy frost.
2 p. m.	56	Cu-n. 9	SW. 4.			Cool.
9 p. m.	54	Cu-n. 9	0			Comfortable.
6, 7 a. m.	48.5	N. 10.	0		Rainy	Cool.
9 p. m.	54	N. 9.	0		do	Comfortable.
7, 7 a. m.	58.5	N. 9 and fog.	W. 5.		Raining all night.	Clearing (?) and colder; river rose 2 inches.
2 p. m.	65	N. 9 and fog.	0			Clear (?) warming (?).
9 p. m.	50	Cl-cu. 2.	0			Evening clearing (rained during night).
8, 7 a. m.	50	0	0			Bright and warming.
2 p. m.	67.5	Cl-cu. 8.				
9 p. m.	51	Cl-cu. 4.	0			Showery 5 to 8 p. m.
9, 7 a. m.	63	0	NW. 4.			Bright.
2 p. m.	67.5	Cl-cu. 4.	NW. 5.			Temperature creek—55°.
9 p. m.	45	Cl. 3.	0			Cool.

Meteorologic observations along Chandlar and Koyukuk rivers essentially at 7 a. m. and 2 and 9 p. m., from June 19 to September 23, 1899—Continued.

Locality and date.	Tempera- ture.	Clouds: Kind and amount.	Wind: Direc- tion and velocity in miles per hour.	Barometer. (Aneroid.)	Weather.	Remarks.
Koyukuk River— Continued.	Degr. F.					
Aug. 10, 7 a. m.	57	Cl-cu. 2....	NW. 4.	.....	.....	Comfortable.
2 p. m.	68	Cl-cu. 3....	NW. 2.	.....	.....	Cool. Location: Fault Moun- tain at 5,000'.
9 p. m.	58	Cl-cu. 4....	0	.....	.....	Do.
11, 7 a. m.	49	Cl-cu. 2....	NW. 2.	.....	.....	Do.
2 p. m.	69	Cl-cu. 4....	NW. 4.	.....	.....	Fine day.
9 p. m.	58.5	Cl-cu. 4....	W. 4.	.....	.....	Do.
12, 7 a. m.	53.5	Cl-cu. 6....	W. 2.	.....	Rain little in night.	Fair morning.
2 p. m.	74	Cl-cu. 3....	.....	.....	.....	Fine warm day.
9 p. m.	54	Cl-cu. 4....	NNE.	.....	.....	Fair evening.
13, 7 a. m.	52.5	N. 9.....	NNE. 5.	.....	Sprinkled	Threatening.
2 p. m.	54	N. 8.....	NNE. 4.	.....	Sprinkled	Do.
9 p. m.	56	N. 10.....	NNE.	.....	Raining	Do.
14, 7 a. m.	56.5	Cl-cu. 4....	NNE.	.....	Rainy night.....	Clearing.
2 p. m.	69	Cl-cu. 4....	NNE.	.....	Fair .....	.....
9 p. m.	48.5	.....	.....	.....	do .....	.....
15, 7 a. m.	49	Cl-cu. 2....	.....	.....	do	On Myrtle Creek.
2 p. m.	68	Cl-cu. 6....	.....	.....	.....	.....
9 p. m.	52	Cl-cu. 10...	.....	.....	Raining .....	.....
16, 7 a. m.	50	Cl-cu. 10...	.....	.....	.....	Fog.
2 p. m.	66.5	N. 10.....	NNE.	.....	Showery.....	.....
9 p. m.	57	N. 10.....	SW. 6.	.....	do .....	.....
17, 7 a. m.	46	N. 10.....	SW. 4.	.....	Raining	Rained all night.
2 p. m.	52	N. 10.....	SW. 3.	.....	do	Rainy day.
9 p. m.	50	N. 10.....	0	.....	Misty and fog	Rainy and foggy all day.
18, 7 a. m.	46.5	N. 10.....	0	.....	Rainy night.....	Misty and foggy.
9 p. m.	34	0.....	0	.....	.....	Some fog.
19, 7 a. m.	48	S. 2.....	0	.....	.....	Bright, temp. rising.
2 p. m.	63	Cl-cu. 3....	NE. 3.	.....	.....	Do.
9 p. m.	53.5	S. 2.....	NE. 3.	.....	.....	Do.
20, 7 a. m.	52.5	S. 2.....	NE. 4.	.....	.....	Do.
2 p. m.	61	Cl-s. 2....	E.	.....	.....	Fine day.
9 p. m.	50.5	N. 9.....	SW.	.....	Raining	Threatening.
21, 7 a. m.	49.5	Cu-s. 7.....	0	.....	Rainy night.....	Clearing(?).
2 p. m.	59	Cu-n. 8.....	0	.....	.....	Threatening SW.
9 p. m.	49	N. 10.....	0	.....	Rainy .....	.....
22, 7 a. m.	44.5	Cl-s. 8.....	SW. 4.	.....	.....	Cool and clearing(?).
2 p. m.	55	Cu. 7.....	SW. 6.	.....	.....	Fine day.
9 p. m.	46	Cu-s. 8.....	0	.....	.....	Cool and dull.
23, 7 a. m.	43	Cu-s. 9.....	SW. 3.	.....	.....	Do.
2 p. m.	52	Cu-n. 4.....	SW. 4.	.....	Showery.....	Do.
9 p. m.	43.5	S. 2.....	0	.....	Fine.....	Do.
24, 7 a. m.	43	Cu-s. 8.....	SW. 4.	.....	Showery in night.	Do.
2 p. m.	50.5	Cl-s. 2....	SW. 4.	.....	.....	Cool; fine day.
9 p. m.	38	0.....	SW. 4.	.....	.....	Do.
25, 7 a. m.	43	Cl-cu. 3....	SW. 10.	.....	.....	Do.
2 p. m.	52	Cl. 3.....	SW. 9.	.....	.....	Do.
9 p. m.	45	Cl-cu. 2....	0	.....	.....	Do.
26, 7 a. m.	41	Cl. 2.....	SW. 2.	.....	.....	Hazy; cool; fine day.
2 p. m.	53	Cl. 2.....	SW. 4.	.....	.....	Do.
26, 9 p. m.	53	S. 8.....	SW. 2.	.....	Showery.....	Warm; hazy.

Meteorologic observations along Chandler and Koyukuk rivers essentially at 7 a. m. and 2 and 9 p. m., from June 19 to September 23, 1899—Continued.

Locality and date.	Tempera- ture.	Clouds: Kind and amount.	Wind: Direc- tion and velocity in miles per hour.	Barometer. (Aneroid.)	Weather.	Remarks.
Koyukuk River— Continued.	Degr. F.					
Aug. 27, 7 a. m.	54	N. 10	SW. 3.	.....	Rainy all night...	Warm.
2 p. m.	56	N. 10	SW. 4.	.....	Showery	Do.
9 p. m.	53	N. 10	SW. 5.	.....	Raining	Rainy all day.
28, 7 a. m.	48	N. 10	SW. 2.	.....	Rainy	Rainy morning and last night.
2 p. m.	48.5	N. 10	SW. 6.	.....	do	Rainy.
9 p. m.	47.5	Cl-n. 8	SW. 7.	.....	.....	Clearing (river rising).
29, 7 a. m.	47	Cl-n. 8	SW. 6.	.....	.....	Clearing (?).
2 p. m.	52	Cl-n. 7	SW. 10.	.....	Stormy	Clearing (?) (river rising).
9 p. m.	47	Cu. 5	SE. 4.	.....	.....	Showery all day; clearing.
30, 7 a. m.	42	Cl-n. 7	0	.....	Some fog	Clearing (?).
2 p. m.	54	Cu-n. 8	SW. 8.	.....	do	Showers in a. m.
9 p. m.	46.5	Cu-n. 7	0	.....	do	Stormy in p. m.
31, 7 a. m.	43	Cu-n. 5	0	.....	do	Fine morning; clearing (?).
2 p. m.	51	Cl-s. 4	SW. 10.	.....	.....	Fair.
9 p. m.	39	Cl-s. 3	SW. 2.	.....	.....	Fine mackerel sky in north.
Sept. 1, 7 a. m.	36	Hazy	NE. 3.	.....	Some fog	Fine morning; frost.
2 p. m.	60	Hazy 3	SW. 2.	.....	.....	Fine mackerel sky in S. and SE.
9 p. m.	50.5	Cu-n. 8	0	.....	.....	Threatening.
2, 7 a. m.	45.5	Cu-n. 7	0	.....	.....	.....
2 p. m.	52.5	Cl-cu. 2	SSW. 3.	.....	.....	Fair day, somewhat hazy.
9 p. m.	45	Cl-cu. 3	SWW. 2.	.....	.....	Fair evening.
3, 7 a. m.	45	Cl. 3	0	.....	.....	Fair morning.
2 p. m.	61	Cl-s. 4	E. 7.	.....	.....	Fair day.
9 p. m.	52	Cu-s. 7	0	.....	.....	Dubious.
4, 7 a. m.	51	N. 9	0	.....	Showery during night.	Do.
2 p. m.	57	Cu-n. 8	0	.....	.....	Dubious (river 40°).
9 p. m.	51.5	N. 10	0	.....	Rainy p. m.	River fell 1 foot in 24 hours.
5, 7 a. m.	51	N. 10	0	.....	Rainy all night...	.....
2 p. m.	58	N. 10	SE. 4.	.....	Rainy all a. m. ...	River still falling.
9 p. m.	49.5	N. 10	0	.....	Rainy p. m.	River still falling; fell several inches since.
6, 7 a. m.	45	N-s. 9	0	.....	Rainy all night...	Do.
2 p. m.	55	Cu-n. 8	SW. 3.	.....	.....	.....
9 p. m.	47	Cu-s. 5	SW. 1.	.....	.....	Fair day and cooler.
7, 7 a. m.	47.5	Cu-s. 7	0	.....	.....	Cool.
2 p. m.	61	Cl-cu. 3	SW. 10.	.....	.....	Fine day (river 50°).
9 p. m.	47.5	Cu. 2	0	.....	.....	Fine day.
8, 7 a. m.	44	Cl. 1	NE. 12 (?).	.....	.....	Fine morning.
2 p. m.	58.5	Cu-s. 7	NE. 12 (?).	.....	.....	Fine day a. m. (river 51.5°).
9 p. m.	49	Cl-s. 1	NW. 2.	.....	.....	Fine evening.
9, 7 a. m.	44	Cl-s. 2	N. 3.	.....	.....	Fine a. m. (river 48°).
2 p. m.	50.5	S-n. 8	E. 8.	.....	.....	Fine a. m.; threatening now.
9 p. m.	48.5	S-n. 8	0	.....	.....	Moderately fair evening.
10, 7 a. m.	44.5	S-n. 9	0	.....	.....	Dubious (river 49°).
2 p. m.	54.5	Cl-cu. 2	NE. 1.	.....	.....	Cloudy a. m.; p. m. hazy, but fine (river 49°).
9 p. m.	48	N. 8	0	.....	Showery	Fine day.
11, 7 a. m.	47	N. 10	SW. 4.	.....	do	Very foggy and misty.
2 p. m.	53	Cu-s. 4	S. 15.	.....	.....	Fair day (river 50°).
9 p. m.	49	S. 2	0	.....	.....	Fine, cool evening.
12, 7 a. m.	34	Cl-s. 4	0	.....	Fog, low and dense	Fine morning (frost).

Meteorologic observations along Chandlar and Koyukuk rivers essentially at 7 a. m. and 2 and 9 p. m., from June 19 to September 23, 1899—Continued.

Locality and date.	Temperature.	Clouds: Kind and amount.	Wind: Direction and velocity in miles per hour.	Barometer. (Aneroid).	Weather.	Remarks.
Koyukuk River—Continued.	Degr. F.					
Sept. 12, 2 p. m.	52.5	S-Cu.....	E. 2.	.....	Threatening.....	Threatening (river 48.5°).
9 p. m.	49.5	Cu-n. 10....	0	.....	Rainy.....	
13, 7 a. m.	44.5	Cl-s. 2.....	0	.....		Clearing; fair morning.
2 p. m.	52	S-n. 9.....	SW. 12.	.....	Showery.....	Showery and threatening.
Lower Yukon River:						
Sept. 13, 9 p. m.	47.5	Cu-n. 6.....	SW. 16.	.....		Stormy. Location; Koyukuk Station.
14, 7 a. m.	41.5	Cu-s. 4.....	SW. 20.	.....	Rained hard in night.	Stormy, but clearing.
2 p. m.	51	Cu-s. 5.....	SW. 20.	.....	Stormy (?).....	Storming.
9 p. m.	39	S-n. 6.....	SW. 10.	.....		Stormy at Nulato.
15, 7 a. m.	37	S-n. 8.....	SW. 15.	.....	Showery (?).....	Storming.
Nulato:						
Sept. 15, 2 p. m.	48	S-n. 9.....	SW. 10.	.....	Showery.....	Do.
9 p. m.	32	S-n. 4.....	NW. 3.	.....		Cold.
16, 7 a. m.	21	S-cu. 1.....	NE. 2.	.....		Ice 1/4-inch thick; fine morning.
2 p. m.	33	S-cu. 2.....	NE. 9.	.....		Hazy.
9 p. m.	31	10.....	NE. 8.	.....	Snowing hard....	Snowed since 3 p. m., and snowing hard now.
Steamer Weare:						
Sept. 17, 7 a. m.	29.5	10.....	NNW. 3.	.....	do.....	Snowed hard all night; 3 inches.
2 p. m.	.....	10.....	.....	.....	do.....	Snowed most of the day.
9 p. m.	.....	.....	.....	.....	.....	.....
18, 7 a. m.	.....	.....	.....	.....	.....	.....
2 p. m.	.....	.....	.....	.....	.....	.....
Holy Cross:						
Sept. 18, 9 p. m.	.....	.....	.....	.....	.....	.....
19, 7 a. m.	32.5	9.....	SW. 2.	.....	Snowing; scatteringly.	Clearing (?).
2 p. m.	37	6.....	SW. 1.	.....	do.....	Do.
Andreafski:						
Sept. 19, 9 p. m.	33.5	Cl-cu. 4.....	0	.....		Fair, moonlight evening.
20, 7 a. m.	27.5	Cl-cu. 8.....	0	.....	Fog.....	Boat stopped by fog.
Steamer Weare 50 miles below Andreafski:						
Sept. 20, 2 p. m.	37	Cl-cu. 6.....	8.	.....	Some fog.....	Blustery.
9 p. m.	34	10.....	10.	.....	Snowing hard....	Wintry.
Aphoon mouth:						
Sept. 21, 7 a. m.	33.5	N. 8.....	0	.....		Fog.
Norton Sound:						
Sept. 21, 2 p. m.	39	Cl-s. 4.....	SW. 5.	.....	Snowing.....	Fair p. m.
St. Michael:						
Sept. 21, 9 p. m.	35	10.....	W. 2.	.....	do.....	
22, 7 a. m.	34	Cl-s. 10.....	.....	.....	Snowy.....	Threatening.
2 p. m.	35	10.....	Nearly calm.	.....	Snowing.....	Snowed all a. m.
9 p. m.	.....	10.....	Nearly calm.	.....	do.....	Cold.
23, 9 a. m.	Frozen hard.	Cl-cu. 7.....	Nearly calm.	.....		Do.
2 p. m.	.....	Cl-cu. 4.....	SW. 10.	.....	Snowing.....	Do.
9 p. m.	.....	Cl-cu. 6.....	0	.....	do.....	Do.

METEOROLOGIC RECORD FOR 1901, BY W. J. PETERS.

Snow was found to average about 6 feet deep in the Koyukuk Valley in April, and as the preliminary expeditions ascended the north tributaries flowing from the Endicott Mountains in April the depth was found to decrease until the grasses were visible in the floor of the passes. By June this deep snow had practically disappeared from the lowlands. Natives report that north winds blow through the passes of the Endicott Mountains with great force in winter, during which season it is dangerous to travel. It is not only dangerous to face the wind, but there is risk of the sled being broken by its being blown against projections in the smooth ice. Fogs were found on the pass in April and dense haze in July. In both cases this seems to have been blown in from the coast.

The following table, showing the temperatures at Uglamie, 9 miles from Point Barrow, is taken from the report of the Ray expedition, 1881-1883:

Temperature observations at Uglamie.
[In degrees Fahrenheit.]

Month.	Mean.	Maximum.	Minimum.
1881.			
November	0	30	-28
December	-18	-----	-----
1882.			
January	-15	20	-45
February	-23	- 2	-52
March	- 4	23	-30
April.....	- 4	32	-23
May	22	37	- 2
June	34	53	24
July	43	65	27
August	38	59	27
September.....	31	51	19
October	9	41	-22
November	- 7	29	-35
December	-17	8	-42
1883.			
January	-17	12	-42
February	- 6	24	-34
March	-13	26	-51
April.....	- 3	16	-30
May	23	38	-14
June	32	51	18
July	36	53	27
August	37	60	22

The highness of the minimum temperatures given here for the winter months, which are 30° to 40° above those of the Koyukuk country in the interior, is obviously due to the moderating influence of the ocean. At Cape Bathurst, northeast of the Mackenzie, in longitude 127° 30', and latitude nearly as far north as that of Point Barrow, the lowest temperature experienced for the past two winters is reported by Mr. Fox, one of the white keepers of a trading post here, to be —36°.

Thunder is rare at Point Barrow, but is known by the natives to occur.

Precipitation at Uglamie, 9 miles from Point Barrow; taken from the report of the Ray expedition, 1881–1883.

Month.	1881.	1882.	1883.
	<i>Inches.</i>	<i>Inches.</i>	<i>Inches.</i>
January		0.44	0.14
February		.04	1.02
March		.51	.14
April		.39	.55
May		.44	.31
June		.61	.30
July		1.39	1.04
August		1.46	1.66
September		1.10	.....
October		1.05	.....
November	0.73	.34	.....
December	.44	.24	.....

METEOROLOGIC RECORD FOR 1885-86, BY LIEUT. G. M. STONEY.

The following temperatures and notes were taken by Stoney^a on upper Kowak River, principally at Fort Cosmos, about 120 miles from the coast, in approximate latitude 66° 53', longitude 157° 23'. As they are continuous throughout a year, they cover a more extended period of time than any other data yet made in the interior of this northern country, and are regarded as one of our most important and reliable records concerning it.

Temperatures on Kowak (Putnam) River.

July, 1885:		
Lowest temperature during month		32° F.
Highest temperature during month		70
Mean temperature during month		49
August, 1885:		
Lowest temperature during month		32° F.
Highest temperature during month		68
Mean temperature during month		47

^aStoney, Lieut. George M., *Naval Explorations in Alaska*, U. S. Naval Institute, Annapolis, Md., 1900, pp. 104–106.

September, 1885:		
Lowest temperature during month		5° F.
Highest temperature during month		60
Mean temperature during month		30
October, 1885:		
Lowest temperature during month		- 4° F.
Highest temperature during month		46
Mean temperature during month		16
November, 1885:		
Lowest temperature during month		-44° F.
Highest temperature during month		15
Mean temperature during month		- 9.5
December, 1885:		
Lowest temperature during month		-65° F.
Highest temperature during month		29
Mean temperature during month		-12.4
January, 1886:		
Lowest temperature during month		-70° F.
Highest temperature during month		31
Mean temperature during month		-13.5
February,* 1886:		
Lowest temperature during month		-65° F.
Highest temperature during month		26
Mean temperature during month		-22.5
March, 1886:		
Lowest temperature during month		-38° F.
Highest temperature during month		36
Mean temperature during month		- 3.8
April, 1886:		
Lowest temperature during month		-22° F.
Highest temperature during month		46
Mean temperature during month		13
May, 1886:		
Lowest temperature during month		14° F.
Highest temperature during month		65
Mean temperature during month		35
June, 1886:		
Lowest temperature during month		32° F.
Highest temperature during month		74
Mean temperature during month		49

* *Note.*—During the month of December, 1885, in one hour the temperature rose 29° F., barometer remaining quite steady. This sudden rise in temperature was closely followed by a terrible gale of wind. The thermometer, not the barometer, indicates an approaching gale. It is dead calm when the thermometer stands low, and during the gales the temperature always goes above zero. The more sudden the rise of thermometer the harder the wind blows and the more quickly it falls. One should watch the thermometer closely and get under shelter if a gale is coming; for neither man nor dog can stand these gales. You must be under shelter. Have seen it snowing—that is a fine snow falling—when there was not a cloud in the sky and very light wind. It is advanced by some that there was a higher wind that carried the snow from the mountain peak.

* Mean temperature February 1 to 20 —33° F.

"When the thermometer is minus, it is denoted (—).

"The temperatures during the months of July and August were taken partly at Fort Cosmos and while at work on the river. The others were taken at Fort Cosmos and an accurate temperature taken every hour by spirit thermometers remaining outside. These were the best (registered) spirit thermometers, made specially for the Government for arctic observation.

"A person can't be too much impressed with the importance of watching the thermometer. I would recommend that the spirit thermometer have the liquid colored, as the white liquid is hard to read. The thermometer should also be protected by a wooden case, leaving only the bulb exposed, and even that should be screened. My observations were the mean of three excellent spirit thermometers."

TEMPERATURES IN 1901.

Following are lists of temperatures encountered by the party. The record was kept by Gaston Philip. As the primary objects of the expedition could be obtained only by making daily moves, which were necessarily made at irregular hours during the twenty-four, these notes are not so complete as might be desired, but they will serve to give a fair idea of the general conditions that prevailed.

Temperatures on Dawson trail at 8 a. m., February to May, 1901.

Date.	Deg. F.	State of atmosphere.	Locality.
Feb. 19	—55	Calm.....	White Horse.
20	—40	do	Do.
21	—25	do	Do.
22	—32	do	Lake Laberge.
23	—22	do	Do.
24	—23	do	Do.
25	—28	do	On cut-off from Lake Laberge to Five Fingers.
26	—14	do	Do.
27	—10	do	Five Fingers.
28	—10	Calm.....	Below Five Fingers.
Mar. 1	0	do	Near Fort Selkirk.
2	0	High wind.....	Fort Selkirk.
3	—45	do	Do.
4	—10	do	30 miles below Fort Selkirk.
5	—10	do	50 miles below Fort Selkirk.
6	0	do	Stewart River.
7	8	do	Near Dawson.
8	16	do	Dawson.
9	16	do	Do.
10	16	do	Do.
11	—12	do	Near Fortymile.
12	0	do	Fortymile.

Temperatures on Dawson trail at 8 a. m., February to May, 1901—Continued.

Date.	Reg. F.	State of atmosphere.	Locality.
Mar. 13	13	.....	Near Eagle City.
17	-23	.....	Mouth of Washington Creek.
18	-22	.....	Do.
19	10	Snowstorm	Charlie River.
20	-10	.....	Do.
21	- 8	.....	Circle.
22	- 4	.....	Near Circle.
23	2	.....	Near Fort Yukon.
24	0	.....	Do.
25	0	.....	Fort Yukon.
26	0	.....	Do.
27	-20	.....	Mouth of Chandlar River.
28	6	.....	On Chandlar River.
29	3	.....	Do.
30	2	High wind	Do.
31	2	.....	Do.
Apr. 1	24	.....	Do.
2	8	.....	Do.
3	6	.....	Do.
4	3	.....	Do.
5	4	High wind	Do.
6	14	.....	Do.
7	18	.....	Do.
8	8	.....	Do.
9	4	.....	Do.
10	6	.....	Do.
11	4	.....	Divide between Chandlar and South Fork, Koyukuk River.
12	4	.....	On South Fork, Koyukuk River.
13	8	.....	Slate Creek.
14	3	.....	Koyukuk River near Bettles.
24	4	.....	John River.
25	10	.....	Do.
26	8	.....	Do.
27	2	.....	Do.
28	18	.....	Do.
29	16	.....	Do.
30	14	.....	Do.
May 1	12	.....	Do.
2	22	.....	Do.
3	16	.....	Do.
4	18	.....	Bettles.

Temperatures on Dawson trail at 8 a. m., February to May, 1901—Continued.

Date.	Deg. F.	State of atmosphere.	Locality.
May 5	20	-----	Bergman.
6	22	-----	Do.
7	24	-----	Do.
8	27	-----	Do.
9	12	-----	Do.

Temperature at morning, noon, and evening at localities between Bergman and Arctic coast.

Date.	a. m.	Noon.	p. m.	Atmosphere.	Locality.
	<i>Deg. F.</i>	<i>Deg. F.</i>	<i>Deg. F.</i>		
May 1	19	33	26	-----	Bergman.
2	14	44	-----	-----	Do.
9	19	33	26	-----	Do.
10	14	44	24	-----	Do.
11	14	34	24	-----	Do.
12	34	35	25	-----	Do.
13	33	36	31	-----	Do.
14	35	38	31	-----	Do.
15	35	-----	36	-----	Do.
16	30	-----	31	-----	Do.
17	31	40	26	-----	Do.
18	28	-----	38	-----	Do.
19	35	39	42	-----	Do.
20	43	56	-----	-----	Do.
21	48	44	40	-----	Do.
22	37	45	41	Rain, 0.02 inch; light wind north ..	Do.
23	37	45	38	-----	Do.
24	40	45	43	Fair.....	Do.
25	49	51	46	do	Do.
26	44	46	42	do	Do.
27	46	52	40	do	Do.
28	43	49	43	Rain	Do.
29	50	48	38	Snow for 36 hours.....	Do.
30	32	43	33	Snow; precipitation to date, 0.67...	Do.
31	41	42	41	-----	Do.
June 1	36	39	-----	Rain	Do.
2	42	45	42	-----	Do.
3	51	52	51	-----	Do.
4	53	57	54	-----	Do.
5	58	50	45	Wind southwest, cloudy; rain, 0.03.	Do.
6	38	44	37	Snow.....	Do.

Temperature at morning, noon, and evening at localities between Bergman and Arctic coast—Continued.

Date.	a. m.	Noon.	p. m.	Atmosphere.	Locality.
	<i>Deg. F.</i>	<i>Deg. F.</i>	<i>Deg. F.</i>		
June 7	35	45		Snow.....	Bergman.
13 ^a	55		40	Fair.....	Do.
14	42		62	do.....	John River.
15	51		55	do.....	Do.
16	60		63	Fair, light wind southwest.....	Do.
17	67	67	52	Rain 6. p. m. to 8 p. m., 0.01.....	Do.
18	57		60	Cloudy.....	Do.
19	62	68	64	Fair.....	Do.
20	63		64	do.....	Do.
21	61		60	Cloudy.....	Do.
22	56		58	Fair.....	Do.
23	56		55	do.....	Do.
24	56		49	Fair; rain, 0.09.....	Do.
25	48		48	Rain, 0.26.....	Do.
26	42	52	52	Rain, 0.20; wind south.....	Do.
27	48	68	62	Fair.....	Do.
28	58	71	62	Fair; temperature (water) 52°.....	Do.
29	51		54	Rain, 0.02.....	Do.
30	58	60		Fair.....	Do.
July 1	56		55	do.....	Do.
2				Rain, 0.04.....	Do.
3	57		57	Light snow.....	Do.
4	50		44	Rain, 0.08.....	Do.
5	50		57	Fair, wind northwest.....	Do.
6	60		65	Fair.....	Do.
7	60		54	do.....	Do.
8	64		64	do.....	Do.
9	57		52	Drizzling rain.....	Do.
10	50		49	do.....	Do.
11	47		49		Do.
12	53		55		Do.
14	44		42	Rain, 0.20; strong wind north.....	Do.
15	44		51	Fair, light wind north.....	Do.
16	5				Do.
18			61	Fair, cloudy, wind south.....	Do.
19			63		Do.
20	62			Fair.....	Do.
21	68	80	70	do.....	Koyukuk-Colville divide.
22	72	74	72	do.....	Do.
23	68		60	do.....	Do.

^a Most of the dates that follow appear on the accompanying maps, Pls. II and III, and designate the localities at or near which the respective observations were made.

Temperature at morning, noon, and evening at localities between Bergman and Arctic coast—Continued.

Date.	a. m.	Noon.	p. m.	Atmosphere.	Locality.
	Deg. F.	Deg. F.	Deg. F.		
July 24	76	85	80	Light showers	Anaktuvuk River.
25	68	.....	83	Cloudy	Do.
26	66	.....	60	Fair	Do.
27	62	.....	52	Rain, 0.20	Do.
28	54	.....	50	Rain, 0.17	Do.
29	34	36	36	Rain, 0.27	Do.
30	41	.....	50	Rain, 0.05	Do.
31	44	.....	.....	Fair	Do.
Aug. 1	55	.....	64	do	Do.
2	62	74	69	Fair, hazy	Do.
3	44	69	64	Fair, smoky	Do.
4	52	67	62	do	Do.
5	54	63	58	Fair	Do.
6	60	65	60	..... .....	Do.
7	60	58	64	Cloudy	Do.
8	44	52	48	Rain 0.04	Do.
9	46	50	44	River temperature 52°	Colville River.
10	43	48	47	Cloudy, drizzling rain; river temperature 50°	Do.
11	48	52	42	Cloudy	Do.
12	43	52	60	do	Do.
13	48	55	51	do	Colville River delta.
14	40	45	52	Light showers	Do.
15	38	42	40	Cloudy, sleet and rain; wind south	Do.
16	38	42	42	Fair	Do.
17	38	40	43	..... .....	Harrison Bay.
18	38	38	38	Cloudy, snow	Do.
19	52	44	42	Fair	Do.
20	44	46	44	..... .....	Do.
21	39	50	52	Fair	Near Cape Halkett.
22	38	42	40	..... .....	Pitt Point.
23	42	42	42	..... .....	Smith Bay.
24	42	39	39	Cloudy, wind east	Do.
25	37	38	36	Cloudy, rainy, strong wind east	Do.
26	36	36	33	Snowsqualls, all day strong wind east	Do.
27	32	33	32	Snow squalls, strong wind	Do.
28	32	32	32	Strong wind east	Do.
29	31	34	32	Cloudy, wind east	Do.
30	32	32	32	..... .....	Do.
31	33	33	32	Cloudy, snow squalls	Do.
Sept. 1	32	32	32	Wind northeast	Do.

Temperature at morning, noon, and evening at localities between Bergman and Arctic coast—Continued.

Date.	a. m.	Noon.	p. m.	Atmosphere.	Locality.
	Deg. F.	Deg. F.	Deg. F.		
Sept. 2	31	33	35	Snow squalls.....	Sinclair River.
3	35	35	35	Clear.....	Off Dease Inlet.
4	36	36	36	do.....	Cape Smyth.
5	36	36	36	do.....	Near Refuge Inlet.
6	37	35	32	do.....	Do.
7	34	34	34	do.....	Do.
8	35	.....	35	do.....	Peard Bay.
9	33	.....	31	do.....	Off Belcher Point.
10	30	.....	30	do.....	Off Wainwright Inlet.
11	32	.....	33	do.....	Near Wainwright Inlet.
12	33	.....	33	do.....	Do.
13	32	.....	32	do.....	Off Icy Cape.
14	35	.....	38	do.....	Off Point Lay.
15	38	.....	38	do.....	Near Cape Beaufort.
16	36	.....	36	do.....	Do.
17	31	.....	30	do.....	Cape Beaufort.
18	36	.....	.....	.....do.....	Off Cape Sabine.

The minimum temperatures recorded for the Koyukuk district at Coldfoot are reported to be -80° and even lower, but the instruments on which these records are based are not known. It is hardly to be supposed, however, that it becomes much colder here than at Circle, Dawson, and other points on the Yukon. Though grass and other feed was scarce, a horse is reported to have wintered at large on North Fork of the Koyukuk, on Mascot Creek, in 1902-3, and appeared to be in fair condition in the spring.

ARCTIC PLANTS COLLECTED.

The following plants, collected on the trip mostly by G. H. Hartman, have been identified, with the exception of the grasses, by Frederick V. Coville and W. F. Wight, botanists of the U. S. Department of Agriculture. The grasses were identified by Mr. Elmer D. Merrill. The localities of collections are designated by camp dates, which latter will be found on the topographic and geologic maps (Pls. II and III).

EQUISETACEÆ. (Horsetail family.)

Equisetum arvense L.

At camp, August 12.

POACEÆ. (Grass family.)

Arctagrostis latifolia (R. Br.) Griseb.

Point Barrow, September 4.

Poa arctica R. Br.

At camp, August 12.

Bromus arcticus Shear.

At camp, August 6.

Elymus innovatus Beal.

Cape Smyth, September 5.

MELANTHACEÆ. (Bunch-flower family.)

Zygadenus elegans Pursh.

At camp, August 5.

SALICACEÆ. (Willow family.)

Salix.

Cape Smyth, September 5.

Salix.

Point Barrow, September 4.

Salix.

At camp, August 12.

Salix.

At camp, August 5.

Salix.

At camp, John River, altitude 1,800 feet, June 20-21.

Salix alaxensis (Anders.) Coville.

John River, June 24; John River Valley flats, July 8; at camp, John River, July 10; at camp, August 5; at camp, August 6; at camp, August 12.

Salix arbusculoides Anders.

At camp, John River, June 28; John River, 1,000 feet above valley, July 8; at camp, John River, July 10; at camp, August 6.

Salix glauca L.

John River, 1,000 feet above valley, July 8; at camp, Arctic slope, July 21; at camp, August 6; at camp, August 12.

Salix niphoclada Rydb. (apparently).

At camp, John River, July 10; at camp, Anaktuvuk River, August 5.

Salix ovalifolia Trautv.

At camp, Colville delta, August 14.

Salix pulchra Cham.

John River, June 24; John River, 1,000 feet above valley, July 8.

Salix richardsoni Hook.

At camp, East Fork of John River, July 16-17.

BETULACEÆ. (Birch family.)

Betula.

At camp, Arctic slope, July 21.

POLYGONACEÆ. (Smartweed family.)

Polygonum plumosum Small.

At camp, July 21; at camp, August 12.

Polygonum viviparum L.

At camp, August 12.

SILENACEÆ. (Pink family.)

Alsine longipes (Goldie) Colville.

At camp, Colville delta, August 14.

Arenaria laricifolia L.

At camp, John River, July 10.

Ammodenia.

Cape Smyth, September 5.

RANUNCULACEÆ. (Buttercup family.)

Anemone.

At camp, Arctic slope, July 21.

Anemone.

Low ground near John River, June 15.

Anemone richardsoni Hook.

Low ground near John River, June 15.

PAPAVERACEÆ. (Poppy family.)

Papaver radicum Rottb.

At camp, August 12.

BRASSICACEÆ. (Mustard family.)

Cochlearia.

Cape Smyth, September 5.

Eutrema edwardsii R. Br.

At camp, Colville delta, August 14.

SAXIFRAGACEÆ. (Saxifrage family.)

Saxifraga hirculus L.

At camp, Colville delta, August 14.

Saxifraga oppositifolia L.

At camp, John River, June 26 and 28.

Saxifraga tricuspidata Retz.

At camp, John River, July 10.

Parnassia palustris L.

At camp, Anaktuvuk River, August 5.

ROSACEÆ. (Rose family.)

Potentilla fruticosa L.

At camp, John River, July 10.

Potentilla villosa Pall.

At camp, John River, July 10.

Dryas integrifolia Vahl.

At camp, John River, June 26.

FABACEÆ. (Bean family.)

Lupinus.

At camp, John River, June 28.

Astragalus.

At camp, August 6.

Astragalus.

John River, June 28.

Astragalus.

At camp, John River, June 28.

Astragalus alpinus L.

At camp, August 6.

Aragallus.

At camp, John River, June 28.

Aragallus.

At camp, July 21.

Aragallus.

John River, June 28.

ELÆAGNACEÆ. (Oleaster family.)

Lepargyrea canadensis (L.) Greene.

At camp, John River, June 28.

ONAGRACEÆ. (Evening primrose family.)

Chamaenerion latifolium (L.) Sweet.

At camp, August 5.

APIACEÆ. (Celery family.)

Bupleurum americanum Coult. and Rose.

At camp, August 6.

PYROLACEÆ. (Wintergreen family.)

Pyrola rotundifolia L.

At camp, John River, June 28.

ERICACEÆ. (Heather family.)

Ledum decumbens (Ait.) Lodd.

At camp, Arctic drainage, July 21.

Rhododendron lapponicum (L.) Wahl.

At camp, John River, June 28.

Cassiope tetragona (L.) D. Don.

At camp, John River, altitude 1,800 feet, on north slope, June 20.

Andromeda polifolia L.

At camp, John River, altitude 1,800 feet, on north slope, June 20.

Arctous alpina (L.) Niedenzu.

At camp, August 12.

PRIMULACEÆ. (Primrose family.)

Androsace.

At camp, John River, June 28.

Androsace.

At camp, John River, July 10.

Dodecatheon frigidum Cham. & Schlecht. Shooting star.

SCROPHULARIACEÆ (Figwort family.)

Pedicularis.

At camp, July 21.

Pedicularis verticillata L.

At camp, Anaktuvuk River, August 5.

CICHORIACEÆ (Chicory family.)

Taraxacum.

At camp, Colville delta, August 14.

Crepis nana Richards.

At camp, August 6.

ASTERACEÆ (Aster family.)

Solidago multiradiata Ait.

At camp, Anaktuvuk River, August 5.

Aster.

At camp, Anaktuvuk River, August 5.

Aster sibiricus L.

At camp, August 12.

Erigeron.

At camp, John River, July 10.

Tanacetum.

At camp, August 12.

Artemisia.

At camp, John River, July 10.

Artemisia norvegica Fries.

At camp, August 6.

Artemisia tilesii Ledeb.

At camp, August 12.

Petasites.

At camp, August 12.

Arnica.

At camp, John River, July 12.

Arnica.

At camp, August 12.

Arnica.

At camp, Arctic slope, July 21.

Arnica lessingii (Torr. and Gr.) Greene.

At camp, Anaktuvuk River, August 5.

Senecio.

Point Barrow, September 4.

Senecio lugens Richards.

At camp, August 6.

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